COMMONWEALTH OF PENNSYLVANIA

# DEPARTMENT OF AGRICULTURE.

BULLETIN No. 61.

## THE USE OF

# LIME UPON PENNSYLVANIA SOILS.

*By Dr. WILLIAM FREAR.*

1900.

WM. STANLEY RAY,
STATE PRINTER OF PENNSYLVANIA.
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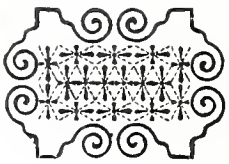

COMMONWEALTH OF PENNSYLVANIA.

# DEPARTMENT OF AGRICULTURE.

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Harrisburg, Pa., April 30, 1900.

The following Bulletin by Dr. William Frear, Chemist of the Pennsylvania State Experiment Station, upon "The Use of Lime as an Aid in Agricultural Production," was undertaken several years ago, at the suggestion of this Department. Practical men have differed radically from each other, and still differ as to the profitableness of the use of lime in promoting the growth of plants, and theorists and scientific teachers also differ as to its physical and chemical effects upon the soil. Lime, in addition to its other virtues, has been found to be of great value as a corrective of soil acidity. Recent investigations show that the state of the soil as to its acidity or alkaline condition affects plants more than was formerly believed, and it is further ascertained that certain plants, grown in acid soils, are not injuriously affected whilst others are seriously injured by this treatment.

Many thousands of dollars are annually expended in Pennsylvania for lime for agricultural use. It is, therefore, important for our farmers to know the latest and best theories and methods for its use, as ascertained by scientific men, attested by careful experiments and the observation of experts, in order that they may be guided in their practice by intelligent direction, rather than by purely empirical methods. Dr. Frear has given careful study to this question, and has had also the benefit of the results of recent investigations by experiment observers in other States, as well as of facts ascertained in a course of experiments conducted at the State Experiment Station in Pennsylvania.

The Bulletin is quite elaborate, is most carefully prepared, and will commend itself to all thoughtful and progressive farmers. It should be carefully preserved for future reference by all who secure a copy.

JOHN HAMILTON,
Secretary of Agriculture.

# LETTER OF TRANSMITTAL.

The Pennsylvania State College,
Agricultural Experiment Station,
State College, Pa., Feb. 28, 1900.

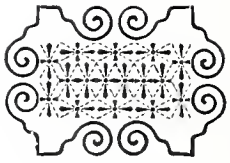
Hon. John Hamilton, Secretary of Agriculture, Harrisburg, Pa.:

Dear Sir: I have the honor herewith to transmit a comprehensive report upon the agricultural use of lime in Pennsylvania and upon certain experiments designed to explain in some degree its beneficial results observed upon certain of the typical soils of our Commonwealth, the inquiry and experiments having been made at your request and in accordance with plans approved by you.

I am under obligation to many public-spirited correspondents in this and other States for valuable information and to my assistants, Mr. Charles A. Browne, Jr., M. A., for aid in compiling the analyses of Pennsylvania limestones; Messrs. W. S. Sweetser, M. S., and M. S. McDowell, M. S., for aid in the investigations upon the organic matter and nitrogen of the soils; and to Messrs. C. W. Norris and C. P. Beistle, B. S., for aid in investigating the physical characters, acidity, carbonatation and the potash and phosphoric acid of the soils. I am also especially indebted to the gentlemen through whose intelligent observation and careful work I was enabled to secure samples of Pennsylvania soils adapted to the proposed laboratory studies, Messrs. L. W. Lighty, Hon. S. M. Wherry, John Moyer, J. S. Biddle, Ed. Anderson and Joel Herr. In the discussion of the subject numerous references have been made to the most important observations and experiments made elsewhere, in order that the use of lime, which is more largely employed in Pennsylvania than in any other portion of the Western Hemisphere, may be more discriminately and economically practised.

Very respectfully,

WILLIAM FREAR.



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# THE AGRICULTURAL USE OF LIME IN PENNSYLVANIA.

## HISTORY.

The use of lime, or "burnt lime," as it is sometimes called, as a means of increasing the productiveness of soils dates back for many centuries. Existing evidences indicate that other calcareous substances, such as marl and wood-ashes, were used as fertilizers in a number of localities long before lime itself was employed for a similar purpose. The most ancient writers of Europe dealing with agricultural processes, refer to their use. Pliny (died A. D. 79) speaks of the application by the Greeks of marl to certain heavy soils as though the custom were one long known, and the Roman general, Varro (died B. C. 28), describes the applications of marl practised by the peoples dwelling in Britain and Gaul.

A. Dickson,* who has made a careful study of the Greek and Latin writers, asserts that lime was not used for agricultural purposes until about the time of Pliny, although its property as a mortar-making substance was well known long before. Cato (died B. C. 150), who wrote of the agriculture of his times, is, however, quoted by Loudon,† as follows: "If you cannot sell wood and twigs, and have no stone that will burn into lime, make charcoal of the wood, and burn in the corn (grain) fields the twigs and small branches that remain." Cato also gives a careful description of the construction of a lime kiln, which was apparently of the type known to-day as a "flame kiln." Loudon infers from the passage quoted that the lime was to be applied to the land, but it is not a necessary conclusion; the use of the waste twigs and faggots to yield wood-ashes for application to the land, in case they cannot be sold or better used for burning lime, is the only distinct recommendation contained in the sentence.

The application of lime was, in Pliny's time, confined by the Roman farmer chiefly to his vineyards and olive orchards; it was also quite a good deal used to hasten the maturity of fruiting of the cherry; but as to its use for ordinary farm crops, while it was occasionally practised, there is no indication that the practise was at all general.

*Husbandry of the Ancients, 1807, I, 330.
†Encyclopaedia of Agriculture, 6th ed., 1869, p. 25.

The Chinese, whose civilization stretches away beyond historical records, and whose agriculture is, in many ways, very advanced, esteem wood-ashes as the very best of manures. While they are aware, says Loudon,* of the fertilizing value of lime, they use it chiefly for the purpose of destroying insects.

During the Dark Ages following the decay of Roman civilization, social and political confusion almost entirely suppressed intensive and skilled agriculture, except as its best traditions were here and there preserved by the studious inmates of an occasional monastery; of this period, there is little agricultural record. It is clear, however, that the practice of liming had meanwhile been more or less continuously kept up. Sir Anthony Fitzherbert, the first prominent English writer on agriculture, in "The Book of Husbandry" (London, 1523), strongly urges the use of both lime and marl; and Gervase Markham, in "The Countrey Farme" (London, 1616), which is chiefly a compilation from the French, Italian and Spanish writers of the sixteenth century, mentions lime as an important addition to many garden soils and, for general cultures, to cold soils in particular.

Since those days, the application of lime has been continued in all those European countries where agriculture exhibits the highest degree of advancement, though with great differences in the manner of use, to which reference will later be made in the discussion of the various more important practical questions concerning liming. More particularly has the practice obtained in Scotland, Wales and the northern and western counties of England—that is, in the more humid regions.

In a private letter, Prof. R. Warington, of the University of Cambridge, long chemist to the Rothamsted Experiment Station, says: "Before the introduction of artificial manures, lime was, next to dung, the commonest manure employed by farmers in England. The use of lime has, in recent years, much diminished. A return to the former practice would be, in some cases, decidedly beneficial. * * In this neighborhood (Rothamsted) in which the subsoil of the fields is chalk, it was a common practice to sink pits into the subsoil and to spread over the fields the chalk brought up from below. * * The analysis of the Rothamsted soil shows that the first nine inches contains about five times as much lime as the second or third nine inches, a relation most unusual in the case of natural soils, and arising apparently from the ancient application of chalk to the land."

In Belgium, in those regions in Germany where the heavier soils prevail, and in France upon the lighter granitic soils, it is also much used.

Dehérain† states the revival of the use of lime in France did not

*Encyclopaedia of Agriculture, 161.
†Traite de Chimie Agricole, 516-7.

in all probability, occur until the beginning of the seventeenth century, and quotes from Oliver de Serres, *Theatre d'Agriculture* (I, 127), to the effect that its use had been followed for a long time in the districts of Gueldres and of Juilliers. At the present time, Dehérain states, the use of lime and of marl has wrought a veritable agricultural transformation in Mayenne, Sarthe, Limousin and Sologne.

It was naturally among the first materials which the European settlers in the New World used when bringing into tillage soils requiring especial treatment, such as swampy lands and very heavy clays. John Spurrier, in "The Practical Farmer" (Wilmington, Del., 1793, a subscription book numbering among its subscribers "George Washington, Esq., President of the United States"), one of the earliest American works on agriculture, treats quite fully of the value of lime in the amendment of such soils and shows a practical acquaintance with the results of its use, though, like other writers of the period, he offers very quaint theories to account for its action. Prior to the introduction of the modern commercial fertilizers, the common calcareous manures were very largely employed. In Canada and in New York and Pennsylvania, gypsum, or land plaster, was a very common application; where marls were readily accessible, especially in Canada and New Jersey, they were widely used and, despite their bulkiness and the great cost of their transportation, they were often carried many miles by rail for application to general farm lands. Wood ashes have been employed everywhere, Canada ashes still finding a large sale in the New England States, New York and northern Pennsylvania. Leached wood ashes, composed chiefly of carbonate of lime, are much used in New England. The use of burnt lime was especially prevalent in eastern Pennsylvania and New York; in certain localities, however, such as eastern Massachusetts, it is scarcely used at all; its difficult accessibility is not the reason for its disuse in many of these localities.

The introduction of commercial fertilizers, particularly the acidulated lime phosphates, potash salts and soluble nitrogenous fertilizers, greatly affected the use of lime in New York and Pennsylvania. While there are many farmers firmly fixed in the traditions of their fathers, who have clung to the use of stable manure and liming to the total exclusion of the artificial fertilizers, they were more numerous who dropped lime almost entirely out of consideration as a means of soil improvement, and the traveler will see in all those regions where lime was formerly used by all farmers, dismantled lime-kilns on every hand.

This tendency to exclude liming has, however, been strongly combatted; the question of "lime *versus* phosphates" has been mooted in some way or other at nearly every farmers' institute held in the

State, with the expression of highly divergent experiences with the contrasted materials and still more highly divergent theories of their several actions. The writer has been led to believe that, without at all diminishing the importance of the place assigned to the commercial fertilizer in farm practice, the use of lime is coming into renewed favor, and is gradually becoming more general. Many inquiries made of the writer, and many statements made by Pennsylvania farmers indicate, however, that the subject is one upon which much confusion of opinion still exists. Nor is this peculiar to Pennsylvania..

Storer* says: "As matters actually stand, the student is met at the threshold of the inquiry by so many different statements, so many possibilities and probabilities, that the subject is made to seem less clear than it really is. As has been said, the contrast between the current methods and practices of farmers in respect to the use of lime, are very remarkable. Why is it, for example, that so little lime is used in eastern Massachusetts, and why is it that such enormous quantities of it are used in other districts such, for example, as some parts of Pennsylvania, of France and of Germany? Indifference towards lime, or objection to it, is by no means peculiar to this particular locality. It is notorious that in some parts of the world landlords have often absolutely forbidden their tenants by contract from using lime, and the employment of it in agriculture at the present day cannot in any sense be regarded as a general practice."

## LIMING IN NEIGHBORING STATES.

Before entering upon the consideration of Pennsylvania practice, a brief view of that of neighboring states will be of interest.

In Rhode Island, as a consequence of careful investigations made at the Rhode Island Experiment Station, the use of lime upon sandy upland soils has grown very rapidly, although it is only of recent date.

Hon. Geo. T. Powell, of Ghent, N. Y., well known to Pennsylvania farmers as an institute lecturer, writes: "There is no lime used in eastern New York." Dr. L. L. VanSlyke, of the New York State Experiment Station, virtually endorses this statement.

Of the practice in New Jersey, Prof. E. B. Voorhees, Director of the New Jersey Experiment Station, writes, that about one-third of the farmers in the northern and central sections follow it, but the use is decreasing. The quantity used is about the same as formerly, viz: 25 bushels of stone lime per acre, applied once in each period of four or, more commonly, five years. It is most frequently applied to wheat at the time of seeding, being spread after plowing and harrowed in. The lime is sometimes home-burned, but is generally pur-

*Agriculture, 4th ed., Vol. II, p. 139.

chased from dealers at a cost of 9 to 13 cents per bushel, and is hauled by the farmer for a distance of two to six miles. It is not allowed to stand in small heaps before spreading. Its best results are seen upon upland clays and shales.

As to Maryland, Director H. J. Patterson, of the Maryland Experiment Station, says that the use is confined to certain limited sections of the state, and appears, in some localities, to be on the increase. The lime is applied once in eight or ten years to land that it seeded down to grass; the amount applied is commonly fifty to seventy-five bushels, but only twenty to twenty-five bushels in some localities, and there is a general tendency toward the lighter applications. The application is commonly made after plowing, and the lime harrowed in; in some sections, top-dressings on wheat and grass are considerably practiced. The lime is not often allowed to stand in small heaps before application. Both oyster-shell and stone lime are used. Some farmers burn their own lime, but it is, for the most part, purchased of dealers in Pennsylvania, and in Washington, Frederick and Baltimore counties, in northern and northwestern Maryland. The cost at the kiln or warehouse is 8 to 12 cents per bushel, and the distance the lime is hauled is about six miles on the average, a haul of twelve to twenty miles being not infrequent. The effect of the application is especially noticeable in the improved growth of grass and clover, these plants often failing entirely when lime is not used.

Of West Virginia, Prof. L. C. Corbett, of the West Virginia Station, writes that in those sections where lime is easily produced by home-burning, about 10 per cent of the farmers follow the practice, but scarcely 1 per cent. in other sections. The lime is usually home-burned, but the limestone is occasionally hauled two to five miles. The quantity applied is not closely estimated, the abundance increasing as the cost of the lime is less, and one application serves for many years. The application is made directly from the wagon upon plowed ground, and the lime harrowed in. The river bottom soils are never limed, only the heavy clay uplands receiving the application.

In Ohio, says Director Thorne, of the Ohio Agricultural Experiment Station, the use of lime as a means of soil amendment, is very rare.

Leaving the humid regions and turning to the states possessed of a more or less arid climate, Prof. E. W. Hilgard, Director of the California Experiment Station, says of California: "Liming and marling are scarcely at all practised in this state, owing to the fact that nearly all the soils at present cultivated contain an excess of calcic carbonate, manifested either by effervescence with acid or the blueing of litmus paper after twenty minutes. The average lime content of California soils, as determined by extraction with hydro-

chloric acid, is over 1 per cent., and the character of the vegetation is almost throughout 'calciphile' (lime-loving). In a few cases where very heavy clay soils have been found poor in lime, I have recommended the use of quick-lime or marl, and it has been done with very good effect; as, also, at a few points in the 'tule' lands—coast marshes—bearing sour grasses. But even in these acidity is rather the exception than the rule, on account of the large proportion of lime contained in the river alluvium."

Speaking of the United States at large, Prof. I. P. Roberts* estimates that at least 99 per cent. of the arable land has never been limed, and it not likely to be in the near future—partly because lime is inaccessible, partly because the soil of certain great areas do not require it.

---

## PRESENT PENNSYLVANIA PRACTICE.

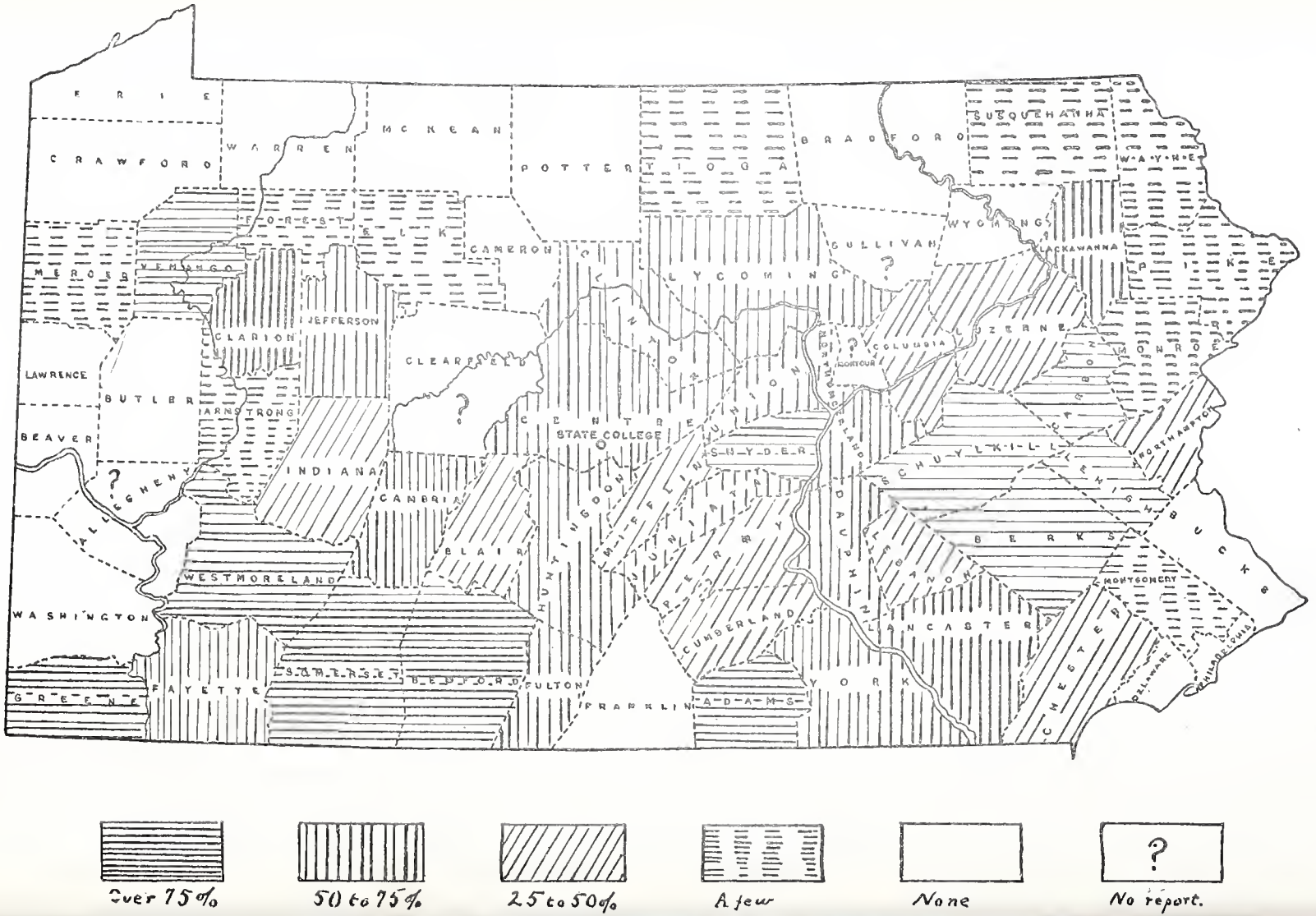
As an introduction to a discussion of the principles involved in the practice of liming, it has been thought that a careful survey of the extent and manner of its use in the several portions of the State would be valuable.

Accordingly, two series of questions were framed to cover the more important points of practice, and submitted respectively to a number of well-informed farmers in each county of the State, and to those lime dealers and burners whose addresses could be secured. The writer is indebted to a large proportion of the gentlemen to whom these queries were addressed, for their full and careful replies. From these replies, the statements of the practice that are given below in the various portions of the State have been compiled. The names of the several correspondents who have given this valuable assistance are given in Appendix A.

### Varying Extent of Practice.

The proportion of farmers in the several counties who use lime has been reported by the correspondents. The answers from the same county are often quite divergent, owing, doubtless, to the fact that because of differences in local conditions, one section of a county uses lime more than another. Necessarily, the number of correspondents from each county was too small to give a perfectly true representation of the extent to which lime is used. The percentage of farmers in each county who use lime upon their soils, whether with frequency or not, as gathered from the correspondence, is shown

*The Fertility of the Land, 1897, p. 305.


ERIE
CRAWFORD
WARREN
MCKEAN
POTTER
TIOGA
BRADFORD
SUSQUEHANNA
WAYNE
FOREST
CAMERON
WYOMING
SULLIVAN
LACKAWANNA
MERCER
VENANGO
CLARION
JEFFERSON
CLINTON
LYCOMING
COLUMBIA
LUZERNE
LAWRENCE
BUTLER
ARMSTRONG
CLEARFIELD
MONTOUR
NORTHUMBERLAND
BEAVER
CENTRE
STATE COLLEGE
SNYDER
UNION
SCHUYLKILL
NORTHAMPTON
ALLEGHENY
INDIANA
CAMBRIA
BERKS
BLAIR
HUNTINGDON
MIFFLIN
JUNIATA
DAUPHIN
LEBANON
MONTGOMERY
BUCKS
WESTMORELAND
CUMBERLAND
LANCASTER
CHESTER
DELAWARE
PHILADELPHIA
WASHINGTON
SOMERSET
BEDFORD
FULTON
YORK
GREENE
FAYETTE
FRANKLIN
ADAMS
Over 75%
50 to 75%
25 to 50%
A few
None
No report.

upon the accompanying map. When a percentage of less than five was reported, the use was considered as probably experimental and no representation made for it.

Of the sixty-three counties reporting, sixteen show no use of lime; in ten or more, it is used by only a few farmers, and in ten or more, by less than half, while in ten, it is said to be used to some extent by 75 to 100 per cent. of the farmers. The greater use is found in the eastern and southern parts of the State; with a few marked exceptions, the least on the extreme northern and western borders. As will be seen in a later presentation of the cost of lime in the several localities, one reason for its lack of application there is the high cost.

From this showing, it is very probable that the use of lime is far more prevalent in Pennsylvania than in any other American locality. The above statement gives no just notion of the soil area to which lime is applied. The surface of Pennsylvania is greatly broken into mountain, ravine and broad river valley. The rocks from which its soils are formed represent most of the well-known geological formations of North America. There is, in consequence, an almost bewildering variety of soil. The use of lime in each locality is largely restricted to specific kinds of land and no data are readily accessible to permit an estimation of the total farm area of Pennsylvania upon which liming is practised.

### SOILS UPON WHICH LIME IS USED.

The inquiry as to the nature of the lands in each locality giving the best results from the application of lime, resulted in a number of general statements to which all agreed:

All soils, when rich in humus, whether new land or old soils long down in grass or heavily manured, respond well to liming, the lighter soils more promptly. It is used in large quantity on the "gladey" lands of Greene county and on certain low-lying black mucks in Snyder county.

With few exceptions, most excellent results are obtained on heavy clay soils, though the benefit often fails to appear if they are low-lying, wet and ill-drained; upland clays seem to give the best results. The white and bluish-white clays of Armstrong and Greene counties may be especially mentioned in this connection. In Pike county only is the result on light soil—gravels or sands—reported superior to that on clay.

"Limestone" land, which is usually clayey in nature, is commonly reported as benefitted by liming, but reports from Bedford county place the results on limestone soil with those on sand, and reports from Lehigh county say that these soils respond least to liming, particularly when the stone lies near the surface. Some limestones

leave a sand, instead of a clay; whether it is so in these cases has not been ascertained.

Sandy soils and bottom lands, except when richly supplied with humus, are usually reported to respond least to liming, but beneficial results are reported from Forest county from applications to soils that had lost their surface layers by flood. Report from Huntingdon county mentions a *heavy* sandy soil in a creek bottom, benefitted by liming, and in Lancaster county, with its broad belt of limestone clay land, the sandy soils are reported to respond best to the treatment.

Distinctly gravelly soils are commonly reported as responding well to liming, sometimes loam better than clay; but certain gravelly soils of Columbia, Indiana and Schuylkill show little benefit. Burning out of humus by heavy liming is noted from Cambria.

Certain soils received special mention in the several counties, and the facts concerning these are given below by counties:

Adams.—Ironstone soils especially benefitted; *blue* shales distinctly injured, *red* shales not.

Armstrong.—Excellent result on spouty clay, impregnated with ferrous sulfate, lying below coal outcrop.

Bedford.—Excellent results on upland slate and red shale soils.

Blair.—Much less effect on red shale than on limestone land.

Carbon.—Red shale ridge requires liming for clover.

Centre.—Light upland soils on spurs of Alleghenies respond liberally to its use for grass.

Clarion.—Light upland sandy soil—chestnut land, and clay, respond best.

Clinton.—Best results on red shale.

Cumberland.—Most beneficial on black slate.

Dauphin.—Flint, red shale and yellow slate soils respond well.

Elk.—Good on clay below coal outcrop, which yields an acid soil.

Franklin and Fulton.—Slate benefitted by judicious applications, often showing best result.

Huntingdon.—Slate lands do well, but can not bear heavy liming.

Indiana.—Slate land stands next to clay in benefit received.

Juniata.—Has little but quick results on shale, least on land underlaid with iron.

Lancaster.—Upland slate shows good results.

Lycoming.—Best results on red and gray shales.

Northampton.—Quite good on gravel and slate lands when new.

Schuylkill.—Best on red loam.

Somerset.—Best on red soils.

Tioga.—Better on red shale than on sand.

Union.—Slates respond least.

Venango.—Dry loam and sands respond well.

Washington.—On red shale there are no good results.

These statements tend to show that slate and shale lands com-

monly respond well to liming, though with some sharp exceptions, which are, probably, due to the difference in the extent to which the rocks forming the soils have broken down, some slates in particular breaking down very slowly and imperfectly.

In response to questions concerning the effect of liming upon the qualities of the soil, it is almost without exception answered that the heavy soils are made lighter, more porous and more easily tilled, and that they regulate the moisture supply more perfectly, so that crops growing upon them suffer less in extremely wet or extremely dry seasons than they did upon the same soil before liming. Of the lighter soils (gravels, shales and slates), it is said that they respond quickly to small applications and are made more compact and better able to retain moisture, but that with large applications they burn out or lose their humus to too great an extent.

### TENDENCY TOWARD INCREASED USE OF LIME.

Irrespective of the methods of its use, the replies indicate that there is a very general tendency to return to a judicious use of liming for special purposes. Of eighty-four correspondents making reply upon this point, one-half state that its use is again on the increase in their respective localities, and only seven distinctly affirm that in their neighborhoods its use is decreasing.

Pennsylvania practice as to the methods of its use, shows wide divergences.

### CROPS LIMED.

Considering first the nature of the crop to which it is applied: In most counties it is reported as being applied to ground preparing for corn, either before or after plowing; but in Blair, Bucks, Centre, Cameron, Crawford, Fayette, Forest, Pike, Susquehanna, Tioga, Venango, Washington, Wyoming and in certain sections of Cambria, Franklin, Huntingdon, Luzerne, Monroe, Northampton and Schuylkill it is either never so applied or with less frequency than upon grass or cereals. The prevailing custom is to plow the sod under, most often during the fall and winter, and apply the lime, after first harrowing and rolling, which operations are then repeated to secure the perfect admixture with the surface soil. In Adams, Armstrong, Bedford, Blair, Clinton, Dauphin, Lawrence, Northumberland, Tioga, Union and in some sections of Jefferson, Lebanon, Lehigh, Snyder and Somerset counties the lime is more commonly applied to the sod before plowing, during the summer if the plowing is to be done in the fall, or during the later fall and winter, if the plowing is deferred until springtime. Many of the correspondents remark that where lime is plowed under with the sod, especial care is taken to have the plowing shallow.

The occasional use of lime upon wheat is reported from nearly all localities, specific statements concerning it being absent only from reports of correspondents living in Berks, Clinton, Dauphin, Delaware, Lackawanna, Lawrence, Lehigh, Susquehanna, Washington and Wayne counties. Its use on rye is specially mentioned in reports from Blair, Fayette, Northampton and Pike counties, though its use on fall grains in general is reported in other localities. It is applied to oats, especially when sown with grass for seeding down, in Cambria, Fayette, Luzerne, Somerset, Susquehanna, Tioga and Wayne counties. When these cereals follow a sod, the application is made either before or after plowing, but when wheat or rye follows oats, the lime is not applied until the oats stubble has been plowed and harrowed.

Very commonly, the application to fall grains and to oats is for the benefit of the following crops of grass and clover. Later applications are not uncommonly made for the latter crops. In one instance, a light top-dressing on fall wheat some little time after seeding is mentioned; more frequently, the application is made after the removal of the grain. Reports from Blair, Bucks, Northampton and Snyder counties state that lime is frequently applied as a top-dressing to wheat stubble; in Centre, it is reported, clover is top-dressed by some; while its application in like manner to meadows and mowing lands is reported from Cameron, Clinton, Franklin, Indiana, Lackawanna, Lehigh, Mercer, Northampton and Washington counties.

Buckwheat land is limed before sowing in Lycoming and Monroe counties.

In Dauphin county, it is stated, lime is frequently used in preparing land for potatoes. It is applied as a top-dressing, with a heavy dressing of manure, upon the plowed ground and is then thoroughly worked into the surface by use of a spring-tooth harrow.

### FREQUENCY OF LIMING.

The replies as to frequency of application can not be readily presented in compact form. In Bedford, Blair, Cumberland, Elk, Franklin, Fulton, Lebanon, Snyder and Westmoreland the applications are not usually made more frequently than once in ten, fifteen or even twenty years. In other districts using lime, it is stated that there is a very distinct tendency to make more frequent and lighter applications, light dressings every three to five years being cited in some localities, the lighter and more frequent dressings being made to light, open soils. The local cost of liming also influences the practice in this respect quite materially.

### AMOUNT OF LIME APPLIED.

The quantities applied vary from 8 to 300 bushels of unslaked lime per acre, an enormous variation, though these extremes are rare,

the lowest extreme being mentioned as occasional in Crawford and in Warren counties, where lime is very costly and very infrequently used; the higher, in Greene and Fayette, where lime and coal are both abundant; even in these localities the application of such large quantities is rare. In most counties the quantities now used range from 50 to 100 bushels. The following tabulation shows where the exceptions to this rule most frequently occur:

| Counties reporting the use of 25 bus. or less. | Counties reporting the use of no more than 50 bus. | Counties reporting the use of over 100 to 200 bus. | Counties reporting the use of over 200 bus. |
|---|---|---|---|
| Adams,<br>Bedford,<br>Chester,<br>Crawford,<br>Dauphin,<br>Luzerne,<br>Lycoming,<br>Monroe,<br>Montgomery,<br>Tioga,<br>Warren. | Adams,<br>Bucks,<br>Cambria,<br>Carbon,<br>Chester,<br>Elk,<br>Forest,<br>Lackawanna,<br>Lebanon,<br>Luzerne,<br>Lycoming,<br>Perry (Eastern part),<br>Susquehanna,<br>Tioga. | Armstrong,<br>Bedford,<br>Cameron,<br>Fayette,<br>Fulton,<br>Huntingdon,<br>Jefferson,<br>Perry (Northern part),<br>Snyder,<br>Somerset. | Clarion,<br>Fayette,<br>Greene,<br>Venango,<br>Westmoreland. |

MANNER OF APPLICATION.

It was formerly the common practice to draw the fresh lime, at any convenient season when the soil was in condition to be least injured by trampling, upon the field, and distribute it in small heaps of a few bushels measure; it was then allowed to stand, often for a long time, until the convenience of the farmer led him to spread it. The merits claimed for this system were that it allowed the greatest latitude of choice for times of hauling and spreading, reduced injury from trampling of the soil and resulted in complete slaking before spreading and dispensed with any necessity for reloading the lime, which is necessary when purchased lime is slaked in large heaps. Notwithstanding these claims, the practice has given way to the better, but less convenient method, of spreading as hauled or of slaking in large heaps, reloading and spreading. The practice still remains, however, in some widely distributed districts, being reported as the usual mode in Armstrong, Bucks, Carbon, Columbia, Cumberland, Dauphin, Elk, Forest, Franklin, Lackawanna, Lehigh, Lycoming, Mercer, Snyder and Union, and in some parts of Adams, Berks, Centre, Juniata, Mifflin, Somerset, Westmoreland and York. But even in these districts it is stated that great care is taken to spread the lime after the first rain or as soon as it is slaked, instead of allowing it to stand indefinitely, as was the too frequent practice in former years.

The spreading is commonly made on a quiet day, from wagon or heap, by means of a shovel. It is often said to be impossible to evenly distribute any amount less than eighty bushels by this method, but the great number of instances in which fifty bushels or less are

applied and the very infrequent use of special machinery for spreading, indicates that the inconvenience is easily overcome. The use of special lime spreaders is not mentioned by any correspondent and is quite uncommon. Those who have the modern manure spreaders find them excellent for an even distribution of lime. Correspondents from Crawford and Fulton counties state that lime is frequently applied in those localities by means of the grain drill; where the lime has been well screened, this method of applying small dressings strongly commends itself.

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## THE LIMESTONES OF PENNSYLVANIA.

There are only three materials that are largely used as sources of lime: Sea shells of various sorts, limestone and, in England, chalk, which is really a very loose-grained, slightly coherent limestone; a fourth material, rarely employed, is coral rock.

### NATURE OF LIME.

The chief constituent of all these materials is calcium carbonate, more commonly spoken of as "carbonate of lime." This substance, when heated to a rather high temperature, gives off carbonic acid gas (carbon dioxid), and there remains lime (calcium oxid), often called "fresh burned," or "caustic" lime, to distinguish it more certainly. The lime remains for some time in lump form, in which form it is called "stone lime." If, however, water is poured or sprinkled upon it, or if it be immersed in water, it breaks down into a fine powder or into a paste or thin fluid, according to the proportion of water used; this process is called "slaking," and really consists in a chemical union of water and the calcium oxid, whereby much heat is liberated; the substances swell and sometimes become hot enough to bubble violently and liberate steam, and there is formed a new compound known as "slaked lime" (calcium hydrate). If stone lime be exposed to the air, it slowly takes up moisture therefrom and falls into powder, containing much calcium hydrate, though the operation proceeds so slowly that the heat liberated passes off gradually and never becomes intense. The calcium hydrate is quite soluble in water, and the lime water so often prescribed by the physician is nothing but a solution of calcium hydrate. Any one who has used lime water has noted that the clear liquid presently forms a white film upon its surface and a white deposit on the sides and bottom of the bottle

containing it; this film and deposit are composed of carbonate of lime, for the hydrate unites very readily with the carbonic acid present in the air, thus returning to the state of chemical combination in which it existed before being subjected to "burning." A similar change occurs in slaked lime exposed, in the form of powder or paste, to the action of the air, and in "air-slaked" lime—that is, in stone-lime slaked slowly by absorption of moisture from the air—there is always quite a large amount of carbonate of lime. Some of these changes will be considered more fully in later paragraphs.

The use of oyster-shell lime is confined to a few sea-coast localities. Inland districts must rely upon the extensive deposits of limestone found in many parts of our country. It will conduce to a better understanding of some questions frequently asked concerning the agricultural uses of lime, if the history and nature of limestone be somewhat carefully considered.

## GEOLOGY OF LIMESTONE FORMATION.

When the globe was first cooled down, the lime combined chiefly, with other bases, in the form of silicates, such as feldspar, amphibole or pyroxene. It is one of the most abundant basic materials of the globe, aluminum and iron alone surpassing it. Prof. F. W. Clarke,* Chief Chemist of the U. S. Geological Survey, estimates that calcium (the metal of which lime is the oxygen compound and which constitutes 71.4 per cent. of lime) makes up 3.77 per cent. of the crust of the earth, taken to a depth of ten miles, 74.5 per cent. of the crust being made of oxygen and silicon. The primitive cystalline rocks of which the crust is supposed to have been at first exclusively formed, contain from 1 to 15 per cent. of lime.

## LIME LIBERATED FROM ROCKS.

These rocks, however, under the action of atmospheric agencies, and especially of carbonic acid and water, gradually weathered or decomposed; as a result of the weathering, the lime was changed from a silicate into the carbonate or acid carbonate, sulfate and nitrate, and these, in turn, were dissoved by the rain and carried off to the ocean. T. Mellard Reade† estimates that at the present time the rainfall annually removes from the average square mile of the earth's surface the following quantities of the more common mineral constituents:

| | Tons. |
|---|---|
| Calcium carbonate, | 50 |
| Calcium sulphate, | 20 |
| Silica, | 7 |

*Bulletin, Philisophical Society of Washington, **2**, 142; Wiley, Agricultural Analysis, I, 23.
†*Cf.* Merrill, Rocks., p. 194.

| | Tons. |
|---|---|
| Magnesium carbonate, | 4 |
| Iron oxid, | 1 |
| Common salt, | 8 |
| Alkaline carbonates and sulphates, | 6 |
| | 96 |

LIME IN SEA WATER.

The composition of the sea water shows quite a different proportion among its several constituents, as illustrated by an analysis by Thorpe and Morton* of the waters of the Irish Sea in the summer of 1870:

| One thousand parts of the sea water contain— | Parts. |
|---|---|
| Sodium chlorid (common salt), | 26.43918 |
| Potassium chlorid, | 0.74619 |
| Magnesium chlorid, | 3.15083 |
| Magnesium bromid, | 0.07052 |
| Magnesium sulfate, | 2.06608 |
| Magnesium carbonate, | Traces. |
| Magnesium nitrate, | 0.00207 |
| Calcium sulfate, | 1.33158 |
| Calcium carbonate, | 0.04754 |
| Lithium chlorid, | Traces. |
| Ammonium chlorid, | 0.00044 |
| Ferrous carbonate, | 0.00503 |
| Silica, | Traces. |
| | 33.85946 |

Estimating the corresponding amounts of lime (calcium oxid) in the annual loss from the earth's surface as found by Reade and in sea water, we find that of the former 37.7 per cent. is lime; of the latter, only 1.7 per cent. In other words, the proportion of lime in sea water is very much less. One cause for this would be found in the removal of lime, in one form or another, from solution. Another fact of interest is that while in the material removed from the earth's crust the carbonate of lime is 2.5 times as abundant as the sulfate; in the sea water the latter is over twenty-eight times as abundant as the carbonate. It might be inferred therefrom that the carbonate had been removed far more rapidly that the sulfate.

The foregoing analysis of sea water shows it to contain one part of carbonate of lime in 20,000 parts of water. Comey, in his *Dictionary of Solubilities* (p. 82), quotes Irvine and Young as stating that one part of the carbonate is, according to its condition and fineness, dissolved by 1,600 to 8,000 parts of sea water, whose solvent action for this substance is greater than that of pure water. It is evident that the lime is not separated or precipitated from the solu-

*Chem. Soc. Journ., 24, 506; Roscoe and Schorlemmer, Treatise, I, 257.

tion in sea water by any method known to the laboratory, and Bischof* states that the ocean at present contains seven times as much carbonic acid as is necessary to retain all the lime in solution, and that for its deposition upon the sea bed living organisms must, therefore, intervene.

CALCIUM CARBONATE SECRETED BY ANIMALS.

As a matter of fact, it is found that the skeletons or shells of many of the lower animals living in the sea are quite largely made up of carbonate of lime; the coral polyps, foraminifera, brachiopods, crustaceans and many lamellibranchs and gasteropods may be cited as belonging to this class. Dana† cites some analyses by S. P. Sharpless that serve to show how largely carbonate of lime is taken up by these organisms.

| | Madrepore coral. Per cent. | Oculina coral. Per cent. | Shell of Terebratula. Per cent. | Oyster shell. Per cent. |
|---|---|---|---|---|
| Calcium carbonate, | 97.19 | 95.37 | 98.39 | 93.90 |
| Calcium phosphate, | 0.78 | 0.84 | 0.61 | 0.50 |
| Calcium sulfate, | ..... | ..... | ..... | 1.40 |
| Magnesium carbonate, | ..... | ..... | ..... | 0.30 |
| Water and organic matter, | 2.81 | 3.79 | 1.00 | 3.90 |
| | 100.78 | 100.00 | 100.00 | 100.00 |

The temperature of the deep sea is too low to allow these forms of life to flourish there. Murray, in reporting the results of the deep-sea explorations of the *Challenger Expedition*, states that the ooze from deep-sea bottoms is of a reddish color, is largely composed of iron oxid and contains little lime; if the rhizopods (foraminifera) and other minute organisms find a fitting home near the surface of the mid-ocean their skeletons are probably dissolved when, after the death of the animal, they slowly sink toward the sea bottom; to give further probability to this theory, analyses of carefully taken samples of water from the lower depths of the deep sea exhibit a larger proportion of lime than is found in the surface waters. The best known lime-secreting organisms of the present day do not live in water deeper than 100 fathoms, nor is the wave action at great depths sufficiently strong to pulverize the shells, coral, etc., whose debris deposited as ocean slime, later becomes the solid bed of limestone. As somewhat illustrating these differences there may be cited certain analyses by Storer‡ of two series of deposits from the sea bottom. (1) a series taken by Lieut. Berryman, U. S. N., off the coast of Nova Scotia, near the northern edges of the Gulf Stream, at depths

*Cited by Reid· Portland Cement, etc., 1877, p. 50.

†Manual of Geology, p. 211.

‡Bulletin of the Bussey Institution, Harvard University, II, 21-3.

of 1,100 to 1,300 fathoms; (2) a series taken by Lieut. Brooke, U. S. N., in the Pacific ocean, between California and China, in the track of the Equatorial and North Pacific currents, at depths of 900 to 3,000 fathoms, chiefly at the greater depths:

| | (1) | (2) |
|---|---|---|
| Silica and sand, | 49.5 to 51.1 | 60.6 to 74.8 |
| Alumina and ferric oxid, | 7.7 to 8.8 | 12.4 to 19.0 |
| Lime, | 17.1 to 18.8 | 1.4 to 2.7 |
| Magnesia, | 1.7 to 1.8 | 1.6 to 3.3 |
| Phosphoric acid, | 0.2 to 0.3 | 0.3 to 2.0 |
| Potash, | 2.1 to 5.3 | 2.1 to 4.1 |

If further evidence is necessary, it is furnished by an examination of the limestone rocks themselves. In many, the shell forms and coral structure are distinctly preserved; under the microscope, the oolitic limestone plainly reveals its animal origin, while the chalk cliffs of southern England are built up almost wholly of the skeletons of foraminifera, over a million of which are requisite to make one cubic inch of chalk.*

## DECOMPOSITION OF CALCIUM SULFATE.

One other fact should be mentioned in accounting for the tremendous deposits of limestone that mark the later history of the earth's crust, namely, that the lime carried to the sea in the form of carbonate is not the only supply from which these great formations were built, but the sulfate also contributed in an important measure. While the loss from the earth's surface in percolating rain, estimated by Reade, and the analysis of sea water by Thorpe and Morton, do not warrant too close comparison, it is clear that, as compared with the common salt, the sea water contains much less sulfate of lime than the waters of percolation. While this compound, as it occurs in gypsum or land plaster, is considered to be one of the less readily destructible compounds known to man, it is well known to plant chemists, that the crops can take it up and that the plant stem, at later stages of growth, is sometimes free from sulfates, under such conditions that the destruction of these salts to furnish sulfur for the building of albuminoids is believed to be established. The decomposition of calcium sulfates to form the sulfid through the activity of lower plant life seems also to be well established, and Olivier and Etard† claim that certain algae may even set sulfur itself free from sulfate of lime. Bernard‡ has noted the liberation of sulfuretted

*Stockbridge, Rocks and Soils, 1895, pp. 35-6.
†Cited by Bernard: Le Calcaire, 1892, p. 245.
‡Loc. cit.

hydrogen as a consequence of the reduction of sulfate of lime in springs and in sea water when abundance of organic matter was present. Buchanan* has shown that the mud of the sea bottom, which is being continually passed through the alimentary tracts of marine animals, has the sulfate of lime it contains reduced under this treatment, to calcium sulfid, the same from that results from the reducing action of water plants to which reference has just been made.

The formation of calcium sulfid being established, it remains to be noted that this substance when dissolved or suspended in water containing carbonic acid, is quickly decomposed with the liberation of sulfuretted hydrogen and the formation of carbonate of lime.† Dehérain‡ states that sulfids formed in soil rich in humus very quickly undergo similar conversion into the corresponding carbonates.

From these facts it is clear that the great limestone formations have drawn for their material not simply upon the lime brought to the sea in the form of carbonate, but also indirectly upon that brought down in the form of sulfate.

### QUANTITIES OF LIME IN PENNSYLVANIA LIMESTONE ROCKS.

The writer estimates, assuming the limestone to have a specific gravity of 2.7 and that it contains roughly an average of 80 per cent. of carbonate of lime, that the Lower Silurian lime formations of Central Pennsylvania, which are about 5,000 feet, or nearly a mile, in thickness, contain upwards of 94,000,000 of tons of calcium carbonate for each square mile of these strata. While the mind can not conceive of such enormous quantities, they serve to impress upon the imagination the wonders of these great geologic changes.

### LATER CHANGES IN LIMESTONE.

These beds, after being raised above the surface of the ocean by some of those frequent changes of level that have marked the history of the earth's crust, have not only become comparatively dry and solidified but, in consequence of pressure, heat and other changes have often assumed a crystalline character such as is exhibited in the pure limestones yielding fine marble. Percolation of surface waters through beds of limestone have dissolved§ much of the carbonate of lime in many localities and strata, leaving the more easily attacked rocks greatly honey-combed; indeed, the great caverns of

*Proc. Roy. Soc., Edinburgh, 1890-1, cited by Merrill, Rocks, p. 204.

†Malaguti, Lecons de chimie, II. p. 150.

‡Traité de chimie agricole, p. 547.

§Note.—The authorities cited by Comey (Dictionary of Solubilities, p. 82) indicate that one part of calcium carbonate requires, according to its condition of subdivision, hardness, etc., from 10,691 to 100,000 parts of water for its solution. If, however, the water be saturated with carbonic acid, as soil water often is in part, only 800 to 3,149 parts are required to dissolve one part of the carbonate, the acid calcium carbonate being thereby formed.

the limestone regions, such as the Mammoth Cave, of Kentucky, Luray Caverns of Virginia, and the interesting Penn's Cave, of Central Pennsylvania, have been formed by this dissolving, percolating process.

### IMPURITIES IN LIMESTONES.

The history of the limestone formations renders it also apparent that great quantities of material other than calcium carbonate must have entered into their composition. The sedimentary limestones in which crystallization does not appear, are colored, not white, and often contain large quantities of *sand*, *clay*, whose deposition upon the shallow sea bottoms from the down-wash of neighboring uplands is readily understood, and of *iron pyrites* (sulfid of iron). When the limestone crystallized, the same conditions brought about changes in the accompanying impurities, and Merrill* mentions, as accessory to crystalline limestone and resulting from such changes or originally present, minerals of the mica, amphibole and pyroxene groups, and frequently sphene, tourmaline, garnets, vesuvianite, apatite, pyrite, graphite, etc.

Owing to their animal origin, the presence of small quantities of *carbonaceous matter* in limestone is not surprising. The dolomitic limestones of Cook county, Ill., contain so much material of a bituminous nature that, when struck by hammer, a distinct odor like that of petroleum is evolved.

For the same reason the presence of *phosphorus* is to be anticipated and, according to Merrill,† the quantity of phosphoric acid in limestone often exceeds that found in either the older siliceous rocks or in other rocks of more modern formation. He gives the following ranges for the percentage of phosphoric acid in some of these rocks:

| | Per cent. |
|---|---|
| Granite, | 0.07— 0.25 |
| Diorite, | 0.18— 1.06 |
| Basalt, | 0.03— 1.18 |
| Limestone, | 0.06—10.00 |
| Shale, | 0.02— 0.25 |
| Sandstone, | 0.00— 0.10 |

The higher percentage given for limestone is one that is very rarely obtained.

The *color* of limestone, marble and travertine (onyx marble) may be white, yellow, brown, red, green, gray, blue or even black. These colorations are sometimes due to carbonaceous matters, sometimes to metallic oxids, iron oxids especially, and sometimes to both. In the white and green varieties, according to investigations of Merrill,‡

*Rocks, p. 162.
†Rocks, pp. 7-8.
‡*Op. cit*, p. 558.

the iron exists as carbonate, in the yellow, brown and red forms, as a more or less hydrated sesquioxid of iron. Bernard* attributes the blue colors of limestone chiefly to organic matters, having found from 1.25 to 2.38 per cent. of such matters in the blue oölithic limestone taken from the bed of the river Marne, in France. The same investigator found, in a clear yellow limestone, in addition to some suspended yellow sesquioxid of iron, to which its color was due, a large quantity of ferrous iron, doubtless present in the form of carbonate. The changes of color which some limestones experience when exposed to the weather are chiefly due to the destruction of the organic matter and to oxidation of the ferrous carbonate and sulfids they contain.

The flint present in many limestones is believed to be derived chiefly from members of the sponge family, which contain considerable silica.

MAGNESIAN LIMESTONES.

There remains for brief consideration the most striking and difficultly explicable foreign constituent of lime, magnesium carbonate, from which few limestones are entirely free, and which is often present in equal molecular proportion with calcium carbonate, forming the mineral *dolomite;* this contains 46.5 per cent. of magnesium carbonate. There are no marine organisms now in existence whose skeletons contain any such proportion of magnesium carbonate. Dana† cites Damour as having found 19 per cent. in corals of the gums *Millepora*, and Forchhammer as having found 6.36 per cent. in *Isis nobilis*, and 2.1 per cent. in the precious coral of the Mediterranean. A single case of magnesian fossil (*Orthoceras*) is mentioned by Dr. T. Sterry Hunt‡ as containing 37.8 per cent.; it was found in the non-magnesian Trenton limestone at Bytown, Canada. Neither is the theory satisfactory that the calcium carbonate was dissolved out by water, leaving behind the magnesium carbonate, whose proportion was thereby increased; no known sea-bed formation of this day contains more than 4 or 5 per cent. of magnesium carbonate; in other forms than dolomite, the magnesium carbonate is more soluble than that of calcium;§ and so large a withdrawal of material from the bed must, it is believed, result in dolomite being universally crumbled or porous; whereas, on the contrary, it is usually more compact than ordinary limestone, and contains fossils of unchanged form.

The more commonly accepted theory for the formation of limestones rich in magnesia is that the sea water has given up magnesia

*Le Calcaire, pp. 193-4.

†Manual of Geology, p. 211.

‡*Ibid*, p. 69.

§Note.—Comey (Dict. Solubilities, p. 87) cites authorities to show that one part of magnesium carbonate requires for solution 5,671 to 17,600 parts of pure water, and from 28 to 8,700 parts of carbonated water. The action of sea water is not stated.

in exchange for lime from the rock. The known facts do not make the theory entirely satisfactory, but it is less objectionable than the others proposed.

Dolomites weather, as a rule, more slowly than pure limestones, though there are exceptions to the rule; they do not give off carbonic acid with effervescence when touched with cold hydrochloric or acetic acid as pure limestones do, and their density is greater, the specific gravity of dolomites ranging from 2.8 to 2.95, while that of pure, compact limestone ranges from 2.6 to 2.8, though both are heavier than the average other rocks from which both are formed.

### LIMESTONE FORMATIONS OF PENNSYLVANIA.

It has been remarked in an earlier paragraph that this state has a great variety of rock materials. J. D. Dana (Manual of Geology, 3d ed., 1879, p. 375), describes the sequence of exposed geological formations in Pennsylvania as follows, beginning with the lowermost or oldest that has been certainly identified:

#### PALAEOZOIC TIME.

*SILURIAN AGE, OR AGE OF INVERTEBRATES:*

**Lower Silurian:**

PRIMORDIAL PERIOD, *Potsdam Epoch:* Sandstone and slates, 3,000 to 4,000 ft. thick.

CANADIAN PERIOD, *Calciferous Epoch:* Calcareous sandstone, 250 ft.

*Quebec and Chazy Epochs:* Magnesian limestone, with some cherty beds, 5,400 ft.

TRENTON PERIOD, *Trenton Epoch:* Limestone, with blue shale, 550 ft.

*Utica Epoch:* Bituminous shale, 400 ft.

*Cincinnati Epoch:* Blue shale and slates, with some thin gray calcareous sandstones, 1,200 ft.

**Upper Silurian:**

NIAGARA PERIOD, *Oneida Epoch:* Gray sandstone and conglomerate, 700 ft.

*Medina Epoch:* Red sandstone and shale, 1,050 ft., and white sandstone, with olive and green shales, 760 ft.; total, 1,810 ft.

*Clinton Epoch:* Shales of various colors, both argillaceous and calcareous, with some limestones, ferruginous sandstones and iron-ore beds, 2,600 ft.

*Niagara Epoch:* Not well defined.

SALINA PERIOD, *Saliferous Epoch:* Variegated marls and shales, some layers of argillaceous limestone, 1,650 ft.

LOWER HELDERBERG PERIOD: Limestone, thin-bedded, with much chert, 350 ft.; encrinal and coralline limestone, 250 ft.; total, 600 ft.

ORISKANY PERIOD, *Oriskany Epoch:* Calcareous shales and calcareous and argillaceous sandstone, 520 ft.

*DEVONIAN AGE, OR AGE OF FISHES:*

CORNIFEROUS PERIOD, *Cauda-galli Epoch:* Silico-calcareous shales, 200 to 300 ft.

*Corniferous Epoch:* Massive blue limestone, 80 ft.

HAMILTON PERIOD, *Marcellus Epoch:* Black and ash-colored slate, with some argillaceous limestones, 800 ft.

*Hamilton Epoch:* Argillaceous and calcareous shales and sandstone, 1,100 ft.

*Genesee Epoch:* Black calcareous slate, 700 ft.

CHEMUNG PERIOD, *Portage Epoch:* Dark gray, flaggy sandstones, with some blue shale, 1,700 ft.

*Chemung Epoch:* Gray, red and olive shales, with gray and red sandstones, 3,200 ft.

CATSKILL PERIOD: Red sandstone and shale, with some conglomerate, 6,000 ft.

*CARBONIFEROUS AGE, OR AGE OF COAL:*

SUB-CARBONIFEROUS PERIOD, *Lower Epoch:* Coarse, gray sandstones and siliceous conglomerate at the east, becoming fine sandstones and shales at the west, 2,660 ft.

*Upper Epoch:* Fine red sandstones and shales, with some limestone, 3,000 ft.

CARBONIFEROUS PERIOD, *Millstone-Grit Epoch:* Siliceous conglomerate, coarse sandstone and shale, including coal beds, 1,100 ft.

*Coal measures*, 2,000 to 3,000 ft.

The more recent explorations of the Second Geological Survey of the State add to the formations given in this list. In the first place, of the rocks of the Azoic Age, or that before the appearance of life on the globe, there is an exposed thickness of 15,000 feet cut by the Schuylkill River, made up of crystalline silicates.

At the other extreme of the geological scale, in the Mesozoic, or Reptilian Age, the Triassic and Cretaceous Periods are distinctly represented, the former by red granitic sandstone, with conglomerate, occasionally impure limestone and rarely shale, and with numerous ridges and dikes of trap rock; in Bucks county the maximum thickness of 27,500 feet is reached. The Cretaceous Period is represented by a brick-clay and gravel formation, occupying a very small area on the Delaware river, just below Trenton; it is a continuation of the formation so distinctly marked in New Jersey by beds of green-sand marl.

In many localities the thicker limestone strata are, of course, buried far below the surface; but even in such case, the deep channel of a river bed or valley often renders them accessible.

The geological map of the State shows that the Lower Silurian limestones form the surface of the land in three, more or less broken belts stretching from the eastern border, in a southwesterly direction, across the southeastern portion of the State. The first belt appears in Bucks, Montgomery, Chester, Lancaster, York and Adams counties; the second in Northampton, Lehigh, Berks, Lebanon, Dauphin, Cumberland and Franklin, while the third, much broken, appears in the numerous parallel curved valleys crossing the southern central portion of the State, in Fulton, Bedford, Perry, Mifflin, Juniata, Blair, Centre, Union, Clinton and Lycoming counties.

The Lower Helderberg limestone formation appears exposed on the mountain sides in very narrow and thin belts, in every county south of Pike, Luzerne, Sullivan and Tioga that lies between the main range of the Allegheny mountains, on the west, and, on the east, the depression crossing the State from Easton to Chambersburg.

In many parts of western Pennsylvania limestones of the coal measures are available.

Replies from correspondents show that in the northern counti s lime is little used, because of its having to be brought in from other localities at great cost, as in case of the small quantities reported in use in Pike, Wayne, Tioga, Cameron, Elk, Forest and Crawford counties; in the western counties south of these, except in Clearfield, for which no report was received, and Beaver, where none is used, many of the farmers are reported as burning their own lime.

Neither time nor space will permit in this paper a discussion of the various strata and localities from which limestone may be obtained in each county of the State. One interested in that question should refer to the reports issued for the county by the Second Geological Survey of Pennsylvania.

As will be made more fully evident in the later discussion of the composition of limes, some knowledge of the composition of a limestone which it is proposed to use should be had before going to any considerable expense in quarrying and burning it.

As a matter of more interest geologically than from a practical point of view, it may be stated that researches by the Kentucky Geological Survey indicate the older limestones to be, as a general rule, richer in soda, phosphoric acid and, when non-magnesian, in carbonate of lime, than are the younger or more recently formed, and correspondingly poorer in silica and insoluble silicates (clay, etc.).

## ANALYSES OF PENNSYLVANIA LIMESTONES.

It has been thought that some value might be derived from a compilation of available analyses of limestones from various localities in the State. Such a compilation, chiefly from the reports of the Second Geological Survey, has been made under the writer's direction by Mr. C. A. Browne, Jr., Assistant Chemist of the Pennsylvania State College Agricultural Experiment Station. These are presented in Appendix B.

## VARIABILITY OF LIMESTONE FROM SAME QUARRY.

It is not probable that the analysis of any single specimen of limestone will correctly represent the entire output from a quarry. The stone varies in composition through the same stratum or bed; but especially are differences of composition observed in the stone from different strata in the same quarry. The most complete study of such variations known to the author is that made by Prof. Peter J. Lesley and Dr. Andrew S. McCreath* upon the composition of the stone of 115 beds exposed in the Walton (McCormick) quarry, opposite Harrisburg. As a typical example of the results obtained, the analyses of rock from the last five beds (Nos. 111-115) may be taken, two samples, one from each end of the sloping bed, having been analyzed in each stratum:

| Bed No. | Thickness of bed. Ft. In. | Calcium carbonate. | | Magnesium carbonate. | | Insoluble matter. | |
|---|---|---|---|---|---|---|---|
| | | Lower sample. | Upper sample. | Lower sample. | Upper sample. | Lower sample. | Upper sample. |
| 111, | 5—6 | 94.5 | 88.4 | 2.7 | 8.3 | 1.9 | 2.6 |
| 112, | 1—7 | 54.4 | 54.4 | 35.2 | 36.2 | 8.4 | 7.7 |
| 113, | 5—6 | 98.1 | 76.2 | 0.9 | 3.7 | 1.0 | 18.2 |
| 114, | 5—6 | 64.6 | 55.4 | 26.2 | 33.8 | 8.5 | 9.7 |
| 115, | 14—6 | 95.1 | 97.7 | 1.9 | 0.9 | 1.7 | 1.4 |

Among the beds retaining their individuality of composition throughout their entire exposure, were some of not more than eight inches thickness.

## RANGE OF COMPOSITION.

An examination of the compiled analyses shows that the several important constituents range in proportion from a faint trace to the following maximum percentage:

| | Per cent. |
|---|---|
| Insoluble, | 80.95 |
| Iron and aluminum oxids, | 10.07 |

*Report of the Second Geological Survey of Pennsylvania, Vol. MM, pp. 311-361, and Final Report, Vol. I, pp. 327-336.

| | Per cent. |
|---|---|
| Calcium carbonate, | 99.30 |
| Magnesium carbonate, | 46.00 |
| Sulfuric acid, | 6.08 |
| Phosphoric acid, | 1.82 |

There were very few true dolomites among these samples. Some of them contained so much impurities that they can not properly be called limestones, but should be termed calcareous shales, sandstones, etc. The quantity of phosphoric acid will scarcely average as high as 0.1 per cent.

## LIMES AND LIME BURNING.

Limestone and other forms of calcium carbonate, it has been remarked in an earlier paragraph, lose carbonic acid when heated and are thereby converted into calcium oxid, or lime. Upon complete burning, 100 pounds of pure calcium carbonate yield 56 pounds of lime.

### TEMPERATURE OF LIME-BURNING.

To effect this decomposition a high temperature is required. Thorpe and Grove, in their treatise on "Manufacturing Chemistry," state that the disengagement of carbonic acid first begins at a temperature of 752 degrees Fahr. (400 degrees C.), a temperature somewhat above the highest employed in a baker's oven, but that this disengagement does not go on fully until a temperature of 1,494 degrees Fahr. (812 degrees C.) is reached.

The conclusions of other observers differ somewhat from those of Thorpe and Grove. Thus, Hans A. Frasch* states that the normal temperature of burning is 850 degrees C. (1,562 degrees Fahr.); that pure calcium carbonate heated for four hours at 615 degrees to 675 degrees C. (1,139 degrees to 1,247 degrees Fahr.), lost none of its carbonic acid; for three hours at 860 degrees to 880 degrees C. (1,580 degrees to 1,616 degrees Fahr.), lost less than 10 per cent., but heated for two hours at 850 degrees C. it lost all its carbonic acid. Heated very intensely the pure carbonate fuses and the escape of the carbonic acid is almost entirely prevented.

As to the effect of heating upon the other constituents of the limestone, whatever the intermediate reactions may be, the final outcome

*The Mineral Industry, Vol. VII (1899), p. 483 *seq.*

is that the carbonates of magnesia and iron give off their carbonic acid, and remain as magnesia and ferric oxid; iron pyrites loses its sulfur and is likewise oxidized; all organic matter is driven off or destroyed, and water, which is present as "quarry water" to the extent of 0.3 to 5 per cent., and often also in some small quantity as water of combination with sulfate of lime, and hydrated iron and aluminum oxids is expelled. Sand and other insoluble impurities are assumed, if the stone be carefully heated, to undergo little or no change. Calcium sulfate and calcium phosphate, if the phosphoric acid present is really combined with calcium rather than iron or aluminum, are supposed to undergo no change in their final state of combination, though no careful investigation of this point is known to the writer.

## LOSSES DURING BURNING.

In the following table a simple example of the loss which the several constituents of a limestone undergo in a perfect burning is given:

| Constituents. | In 100 lbs. of the original stone. Lbs. | Loss. Lbs. | Residual lime. Lbs. | Percentage composition of the fresh-burned lime. |
|---|---|---|---|---|
| Water (both quarry water and water of combination) and organic matter, | 3.00 | 3.00 | ..... | ..... |
| Sand, clay, phosphate of lime, and anhydrous sulfate of lime, and oxids of iron and aluminum, | 7.00 | ..... | 7.00 | †13.75 |
| Calcium carbonate, | 70.00 | 30.80 | 39.20 | 70.07 |
| Magnesium carbonate, | 19.00 | 9.95 | 9.05 | 16.18 |
| Ferrous carbonate, | 1.00 | .38 | *.69 | ..... |
| | 100 00 | 44.13 | 55.94 | 100.00 |

*In its conversion to ferric oxid, 1 part of ferrous carbonate takes up .07 parts of oxygen from the air.

†Excluding the ferric oxid from ferrous carbonate.

That is, there remains none of the water or organic matter, all the sand, clay, etc., besides ferric oxid equivalent to 69 per cent. of the weight of the ferrous carbonate in the limestone, magnesia equivalent to 47.63 per cent. of the magnesium carbonate and lime equivalent to 56 per cent. of the calcium carbonate. These factors may be applied in estimating the yield of lime from limestone whose composition is known.

## YIELD OF LIME.

Several question concerning the yield of lime are frequently asked. 1. How much stone is required to yield a bushel of fresh-burned lime? Taking a stone of the composition first given, and the standard weight of 72 lbs. for the weight of the lime, the answer would be $\frac{100}{56}$ of the

lime (72 lbs.), or 128.6 lbs. With poorer limes, the weight required is less. 2. How much lime will a perch of limestone yield, assuming proper burning? This, evidently, depends upon two things; first, the density of the stone and its freedom from pores, which determine its weight; second, its composition, by which the loss during burning is determined. For illustration, take the two very simple cases of marble and of dolomite, which are each supposed to contain, as the only material other than carbonate, 2 per cent. of water and organic matter. Fair average specific gravities for these substances are, for marble, 2.72; for dolomite, 2.9; so that the weight of a cubic foot of water being 62.5 pounds, the weight of a cubic foot of these rocks would be 170 and 180.25 pounds, respectively; and a perch of the solid material ($24\frac{3}{4}$ cu. ft.) would weigh, for the marble, 4,207.5 lbs.; for the dolomite, 4,234.67 lbs. .The residue from burning 100 lbs. of the marble would be 56 per cent. of 98 lbs. (the amount of carbonate of lime present), or 54.9 lbs., so that one perch would yield 2,309.9 lbs., or $32\frac{5}{8}$ standard bushels of 72 lbs. each. Each 100 lbs. of the dolomite would yield 51.8 per cent. of 98 lbs., or 50.8 lbs. of lime, (lime and magnesia, more correctly), equivalent to a yield of 2,151 lbs., or 29.9 standard bushels, for each perch of the solid stone.

### METHODS OF BURNING.

Lime is burned in Pennsylvania both in "heaps," similar to those for preparing wood-charcoal, and in kilns of various types. Either wood or coal, or in some cases, both, are used as the fuel. The coal used is usually bituminous, of which the "slack," or cheaper grades are often employed.

### BURNING IN HEAPS.

Burning in the "heap" is practiced in Centre county about as follows: A convenient oblong piece of ground is cleared, and leveled if need be, to secure a fit platform. Upon this is laid a layer or two of good cord-wood, better well seasoned. Between the chinks in the cord-wood, shavings, straw or other light kindling is placed. The stone having been reduced to the size of a double fist, sometimes not so small, is laid upon the cord-wood, care being taken to leave chinks between the stones just as between the bricks in a brick kiln; it it preferred that this layer of stone should not exceed six to ten inches. In some cases, temporary wooden flues, filled with straw, are erected, either one at the center or, if the heap is oblong, one near each end, and the stone and coal are built up around them; thus, when they are burned out, a chimney draught or two is secured, which may be damped by pieces of stone or sod. Upon this layer of stone is spread a layer of coal, and upon that a thicker layer of stone (12 inches), and so on, coal and stone alternating until the

oblong heap is topped with smaller stone. The proportion of coal is diminished in the upper layers, the effort being to distribute one-half of the total coal employed in the two lower layers, so as to secure the highest economy possible in this use of the fuel. Fire is then kindled in the straw or shavings; when the flames have communicated themselves to the cord-wood and lowermost layer of coal, and tongues of flame shoot out from the crevices in the sides of the heap, earth, previously loosed by a few turns of the plow about the heap, is rapidly spread over the entire heap, thus damping the draughts and retarding the combustion. Fig. 1 represents crudely this arrangement of the materials in the heap. Steam and smoke slowly escape during the first hours, but later the entire heap, includ-

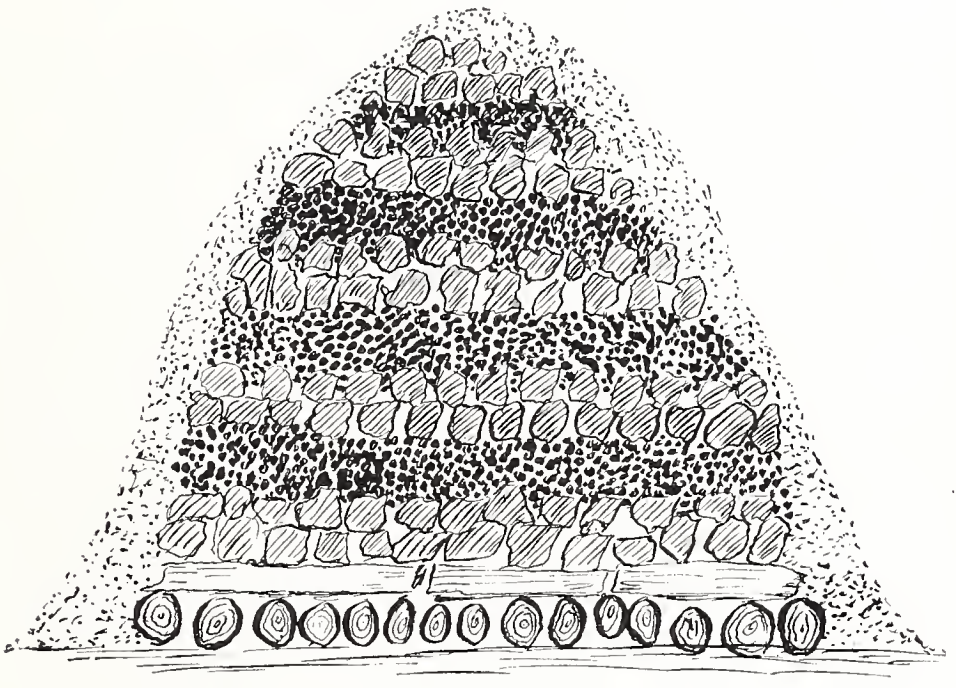

Fig. 1.

ing the outer covering of earth, is heated to a dull red glow. The burning goes on slowly for several days, the interior often being hot for several weeks. When the lower portion of the heap has reached an advanced state of calcination, a portion of the outer layer of lime sometimes slips down; if so, a fresh covering of eath must be promptly applied at the exposed point; otherwise, it will serve as a vent for the heat, and the top and other sides will fail of proper calcination.

In other localities the heap is covered with compact earth or sod before the fire is kindled, a few openings being left at the top, whereby the steam and smoke may escape; these openings are stopped as soon as the smoke has disappeared. Low* states that in England a compact wall is carefully built around the lower portion of the heap,

*Landed Property and Economy of Estates, p. 494.

with proper draught holes, and that the top is covered with turf or mud. "This," he says, "is an expensive method of burning, from the large quantity of fuel required; but from the more slow and gradual combustion, the lime is reckoned superior to that produced by other means." The quantity of fuel used in Centre county is roughtly one ton of coal for each 100 bushels of lime, though a heap of 3,000 bushels is sometimes satisfactorily burned with twenty tons of coal; that is, the ratio of coal to lime ranges from 1:3.5 to 1:5, or, estimating on the basis of compact limestone, yielding about thirty bushels of lime to the perch, one ton of coal would burn from three and one-third to five perches.

Frasch* expresses the fuel requirement in other terms, viz: as 1.25 volumes of coal slack for each six volumes of stone.

### KILN BURNING.

Of kilns there is a great variety in form and construction, but they may be grouped as belonging to one of three types:

A. Intermittent kilns, which require the complete calcination and removal of one charge before another can be introduced.

B. Perpetual kilns, from which the earlier calcined portions can be removed and fresh charges introduced while the burning is in progress. Of these there are two kinds:

a. Ordinary draw-kilns, in which the fuel and stone are introduced in alternate layers.

b. Flame-kilns, into which the stone is introduced, unmixed with fuel.

The *intermittent kiln* is not so frequently used as the draw- and flame-kilns. It is sometimes employed where quite small quantities of lime are to be prepared with the use of wood as fuel. In such kilns, a dome of large pieces of limestone is built within the kiln, the inner walls of the kiln forming the abutment upon which it rests. During the forming of the dome, the stone is supported upon false work. Upon this dome the smaller stone is placed until the kiln has filled. Well-seasoned short-length wood is then set on end upon the grate, with which such kilns should be supplied, and kindled. The draught must be carefully regulated to ensure a gentle heat at the outstart, the fire being gradually increased during eight hours; otherwise, the quarry water in the large stone will be too suddenly converted to steam, rending them and possibly causing the arch to give way. The mass will then have settled about one-sixth and a crow-bar will work easily in it; the top of the kiln is then closed to confine the heat and complete the calcination of the upper layers, which requires ten to twelve hours more. With such kilns, the vertical distribution of heat is very uneven; hence, the kilns are made of rather large

*The Mineral Industry, VII (1899), 483 *seq.*

diameter and low, so that the bottom lime may not be overburnt and the top layers left "raw" or incompletely calcined.

Frasch* states that in such kilns from two to three volumes of hard wood are required for each volume of lime.

The *flame kiln* will be mentioned next. In this kiln the draw-arch is situated below and is independent of the fire-arch; and the latter is always provided with a grate and underlying shallow pit from which the ashes may be removed as necessary. Because of these peculiarities of construction, as well as for the purpose of securing a good draught, flame-kilns are usually given a relatively great height. Also, with the object of securing a more even firing, a single kiln usually has two or more fire arches opening into it from different sides, the fuel being delivered to an elevated platform, from which it is shovelled upon the grate as the burner thinks necessary. Many such kilns have, instead of a circular, horizontal cross section, one of oval form, the diameters being to each other approximately as four to six. Just about the level of the fire arches, the interior of the kiln is divided by a vertical wall, the top of which is narrowed to a sharp ridge, while the thickness of the wall increases toward its base in such manner that the interior of the kiln is divided into two compartments gradually curving out toward the draw-arches. All openings into the kiln are provided with doors, permitting the regulation of the draught. It is claimed for these (1) that they keep the lime free from impurities introduced in the fuel; (2) that the stone is more evenly burned; (3) that they are more convenient in working; (4) and that they are by far the most economical in their fuel requirements. The kiln should have such capacity as to hold from 1.75 to 2 times the amount of stone required for the daily yield of lime desired; the material is subject to the heat for twenty-four to forty-eight hours, and the lime is drawn every six to eight hours as the capacity of the "thimble," or receptacle for the burnt lime in the lower portion of the kiln, may make needful. The saving in fuel, at least when wood is used, is claimed to be at least three-sevenths of that required by intermittent kilns of the same output. Various manufacturers estimate that one cord of wood will burn from 60 to 110 bushels of lime, according to the quality of the fuel and stone and the conditions of burning. Frasch estimates that in the flame-kiln thirty-six to forty pounds of hard wood is required for each cubic foot of lime produced, and that in the Hoffman type of kiln, five pounds of coal slack is sufficient for this volume of lime.

The flame-kiln is, for the production of lime of a very pure, even quality and for economy of fuel, which reaches its highest importance in large operations carried on continuously, to be preferred to any other type of kiln.

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*Loc. cit.

The ordinary *draw-kiln* is, however, far cheaper in construction, and for this reason, is commonly adopted where operations are not extensive and where the inclusion of some ashes from the intermixed fuel is not highly injurious to the use for which the lime is intended. There are many differences in the detail of construction of such kilns. The writer has seen in Somerset county, in a locality where suitable building stone for exterior walls is not readily obtainable, kilns whose outer walls and draw-arch are constructed simply of a crib-work of rough, notched logs; the interior walls were built up somewhat in the form of a peach basket, from thin sandstone found in the neighborhood, laid flat sides horizontal; between this inner shell and the crib work, clay was carefully tamped in forming a retaining wall for the lining of the kiln. Figures 2 and 3, after Gilmore, represent

Fig. 2.

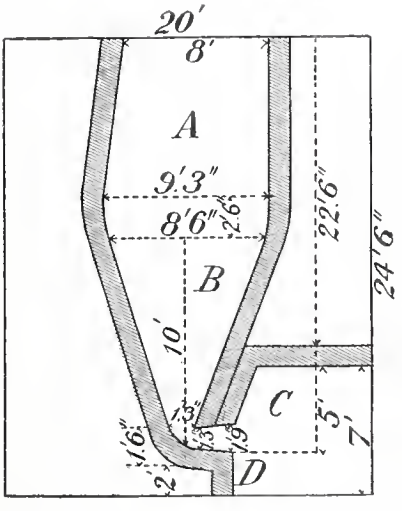
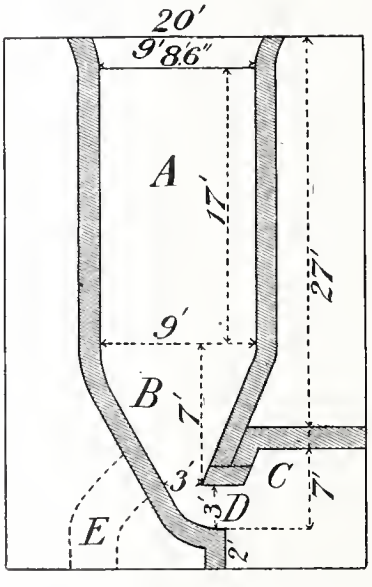



Fig. 2.




A—The body of the kiln; B—The bosh; C—The draw-arch; D—The door; E—Flue proposed by Shortlidge.

cross-sections of two common forms of draw-kilns; that represented by Fig. 3 being most frequently adopted in Pennsylvania. The outer walls are commonly built of limesone, sometimes of brick; instead of being vertical, as represented in the cut, it is preferred that they should have a slight batter. Since they have a tendency to crack and spread near the top after the kiln is heated, it is best to use, to strengthen the upper walls, several sets of iron tie-rods, crossing from side to side in the space between the inner and outer walls of the kiln; these may pass through horizontal, stout strips of timber on the outside to more effectually apply their retaining force; the rods should be secured at the ends by strong nuts, with large washers. The inner wall should be built of the best fire-brick if the kiln is intended for hard use; sometimes satifactory substitutes for fire-brick are found in sandstone and hard clay-slate found in the

locality. The space between the inner and outer walls is commonly filled with well-tamped earth, which serves as a good retaining wall and as an excellent non-conductor of heat. It is often convenient to examine the glowing mass in the middle portions of the kiln and, in case it clogs, as sometimes happens, to be able to stir it down. Both advantages are secured by building into the kiln several two-inch iron tubes that pass from the exterior at convenient points, horizontally through the inner wall; when not in use they are closed by plugs, or caps; they admit a long iron rod by means of which the clogged lime can be poked and worked down. The opening from the interior of the kiln into the draw-arch should be closed by a door, so that the amount of air admitted at that point may be regulated.

By many lime burners the iron shell kiln is being adopted. This is a kiln whose body is formed from boiler iron, lined with fire-brick and supported upon iron pillars or upon an arch of masonry. It may either be simply enclosed within a wooden building or, for better prevention of loss of heat, within a wall of masonry suitably packed with broken stone or earth.

The late Col. Wm. Shortlidge, of McCalmont & Co., the owners of extensive lime kilns at Bellefonte, Pa., a lime manufacturer of many years' experience, mentioned to the writer the difficulty of regulating the draught so as to secure an even calcination, as one of the most serious objections to the ordinary, single arch draw-kiln. As a remedy, he proposed that a ring flue be constructed with its air inlets opening from the sides of the draw-arch and discharging through three or four vertical branches ending in stout iron gratings, about 9 inches by 12 inches, set at the same height in the sloping walls of the bosh of the kiln, so as to introduce air more uniformly to different parts of the kiln. He had already tried a modification of the old form of kiln in which this feature had been imperfectly introduced, and found it to result beneficially. The location of this flue with one of its branches is dotted into the vertical section, Fig. 3, at E. It would be desirable, the writer would suggest, to provide passages, closed with suitable doors let into the sides of the kiln, constructed at right angles to the axis of the draw-arch, for the annular flue will, in time, be stopped by the fine material that passes through the gratings and this dust must be removed to keep the draught in proper regulation.

The location of the kiln also has much to do with the draught. If the latter be poor, the burning is expensively slow. It is well known in regard to chimneys that if their tops be lower than the roof of the house or than the leafy tops of neighboring trees and the wind pass over the roof or tree top toward the chimney, a down-flow of air pours upon it and effectually checks the upward passage of the heated air from the cap or top. A similar checking of the draught

occurs in kilns situated in like manner with reference to a steeply sloping hillside. On the contrary, if the draw-arch face the prevailing wind and be provided with no regulating door, over-burning often occurs because of the occurrence of too fierce a draught.

So important are the points of regulation of draught, fuel proportion and quality of stone and coal to which a skilful burner closely attends, that, according to an experienced lime manufacturer, a flame-kiln of modern construction, with body of oval cross section, $4\frac{1}{2}$ feetx$6\frac{1}{2}$ feet, and a height of 22 feet above the fire arch, which will, under most favorable conditions, yield 500 bushels of lime per diem, yields, in actual practice, with ordinary average stone and ordinary conditions, only 200 to 250 bushels. The same authority states that a kiln having been built, it is common experience to be obliged to materially modify arches, door-ways, etc., to adapt the draught qualities of the kiln to the particular movements of wind currents in the locality of this single kiln.

The variation in the quantity of coal required in this type of kiln ranges, according to computations based upon data given by Gilmore,* from one part to 2.25 to 7.2 parts of the burnt lime. Frasch** states that for three volumes of the stone, one volume of soft coal, one and one-half volumes of coke or three to four volumes of lignite is required. Magnesian limes† and cements require somewhat smaller proportions of fuel. Gilmore‡ states that 3,500 lbs. of anthracite coal is sufficient for 100 barrels of cement of 300 lbs. each, which is a ratio of one part coal to 8.6 parts calcined cement. The coal should be of a low ash content, if possible, to diminish the danger of "clinkering."

The best calcination occurs when the stone is broken into rather small pieces; this is especially true in burning impure limestones, which should be broken to less than six inches in diameter.

In the operation of the ordinary draw-kiln, kindling is placed upon the grate,§ covered with coal followed by stone, coal and stone alternating to the top of the kiln, which is often surmounted by a wooden crib by which its capacity is increased and the heat more fully utilized. In filling the kiln before the burning has begun, the lower coal layers are made unusually thick in proportion to those of stone, for reasons already suggested in discussing the burning in heaps; later, the normal proportions are maintained. Others prefer to fill the kiln one-half to two-thirds with raw stone, then adding a layer of fuel and subsequent layers of stone and fuel as in the charging during the burning; the fuel layer is in such case connected with

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**Loc. cit.*, On Limes, Hydraulic Cements and Mortars, 1864, p. 141.

†Roscoe and Schorlemmer, Treatise on Chemistry, II, Part 1, p. 190.

‡*Op. cit.*, p. 127.

§Many draw-kilns have the lower wall of the bosh terminate, as it approaches the door into the draw-arch, in a grating, below which is a shallow pit.

a core of kindling running from the draw-arch. The object of this arrangement is to secure a more uniform management of the heat; if, however, the coal layer is not ignited from the kindling, the expense of discharging and recharging the kiln is considerable.

### STAGES OF BURNING.

According to H. Reid* there are two distinct stages in the burning of stone; the first, during which water is expelled and organic matter is destroyed; until this is completed, the indication being the disappearance of vapor readily recognized by the expert eye, the application of high heat is wasteful; the second stage is that of "decarbonatation," and is completed when all the carbonic acid that can be profitably removed has been dispelled, which is accomplished at about the temperature of bright redness.

It is difficult to expel the last portions of carbonic acid. The stone burns more rapidly if it is somewhat moist. Many lime burners have been in the habit of using moist wood or of watering the stone with the object of developing steam to promote the expulsion of carbonic acid.

Frasch observes that fresh-quarried stone burns more perfectly than that which has been long exposed to the air and recommends periodic injections of steam or air. But Mahan† regards the practice as disadvantageous because of the increased fuel requirement.

### BURNING IMPURE LIMESTONE.

Impure limestones are especially difficult to calcine uniformly; those containing sand often vitrify at a temperature not much above dull red heat, and the hard, glossy lumps left on cooling are not only of no use to the builder or farmer, but increase the difficulty of handling the other material.

When very impure clayey limestones are burned, the lime unites with the clay, which, as it occurs in the limestone, is insoluble in acids, and forms by union with it silicates that are completely dissolved by acids. Intimate mixtures of pure limestone and certain clays, when burned together, form similar silicates. The practice of clay-burning followed, a few decades ago, in many parts of England and Germany as a means of improving the soil, is believed to have owed its value to the formation in the burnt clay of similar silicates; clay deficient in lime, was not benefitted by burning.

### TIME OF BURNING.

The length of time required for ignition in the draw-kiln is less than in the intermittent kiln. The lime will be partially drawn

*Portland Cement, p. 243.
†Civil Engineering, p. 25 *seq.*

every few hours so far as the burner finds it to have been satisfactorily calcined; no absolute time rule can be laid down.

According to Frasch a kiln of 1,200 to 1,400 cubic feet capacity will turn out 700 to 900 cubic feet per day of twenty-four hours, if ten to twelve charges be drawn during that period. The lime expands in volume from 20 to 25 per cent. during the burning, but retains the shape of the original stone. Pure lime should be burned rapidly, as it slakes better in such case, but if incompletely calcined it forms a basic lime carbonate and is "dead," or incapable of slaking. Compact limestone cannot be so rapidly calcined as the porous varieties, but yields a better lime.

As the lime is drawn, the major portion of the coal ashes can be thrown to one side, but some will remain admixed with the lime.

## WEIGHT OF LIME.

The weight of a bushel of lime is much more variable than is commonly supposed. Lloyd* says "A ton of lime equals about 27 bushels;" that is, a bushel weight is 75 lbs. Roberts† also says, briefly, "75 lbs. of stone lime are sold for a bushel at the kilns at Union Springs, N. Y."

Cook‡ states that a bushel of good stone lime, unslaked, weighs 93 lbs.; of oyster-shell lime, 60 lbs.; of magnesian stone lime, 80 lbs. Legal weights for a bushel of unslaked lime have been established by several states as follows: In Ohio and Michigan, 70 lbs.; in Virginia, Georgia, Illinois, Iowa, Kansas, Nebraska and Colorado, 80 lbs.§. In Pennsylvania, the more commonly accepted bushel weight is 72 lbs.

In view of the range of these figures, it was thought of interest to inquire somewhat more particularly respecting the accurate weight of a struck bushel of the fresh-burnt limes sold in the State. The replies received from a number of lime burners and dealers are tabulated in the second column of the following table:

TABLE 1.—Weight of a Bushel of Lime. (Struck Bushel; in Pounds.)

| Quarry. | Fresh-burned. | Slaked. | Remarks. |
|---|---|---|---|
| Berks county: | | | |
| 1. Near Bechtelsville, on Colebrookdale R. R., M. G. Oberholtzer, Prop'r, ..... | 82 | ..... | Solid, blue stone; 54 c. l., 44, c. m. |
| 2. West branch of Maiden Creek, near Calcium, J. S. Pearson & Co., Prop'r, ..... | 78 | 40 | Stone never analyzed. |
| 3. Near Host, Tulpehocken Twp., Jacob Shaffner, Prop'r, ..... | 78 | 40 | Stone never analyzed, burns to a fine, white lime fit for building. |

*Science of Agriculture, p. 119.

†Fertility of the Land, p. 305.

‡Report of the New Jersey State Agricultural Experiment Station, 1881, p. 31.

§*Cf.* Report, U. S. Dept. Agriculture 1880, p. 227.

TABLE I.—Continued.

| Quarry. | Fresh-burned. | Slaked. | Remarks. |
|---|---|---|---|
| Blair county: | | | |
| 4. Near Union Furnace, on main line P. R. R., Keystone Lime and Stone Co., Tyrone, | 72 | 50 | Slaked weight is for dry-slaked lime; analysis: c. l., 96; c. m., 2 per cent. |
| 5. Stanfield Station, Hollidaysburg and Martinsburg Branch, P. R. R., John Manning, Hollidaysburg, Prop'r, | 72 | 30 | Slaked weight is air-slaked; analysis, 98 per cent. c. l. |
| 6. Frankstown, on P. R. R., J. King McLanahan, Jr., Hollidaysburg, Prop'r, | 72 | ..... | Analysis, 94 per cent. c. l., 3 per cent. c. m. |
| Chester county: | | | |
| 7. Near Avondale, Phila. & Balto. Central R. R., Avondale Lime and Stone Co., Prop'rs, | 80 | 35 | Stone varies from a pure c. l. (fish egg) to a mica schist; stone burned has some magnesia, as it is the only kind in this quarry that will stay in lump during burning. Average composition, 70-80 c. l.; 15-25 c. m. |
| Franklin county: | | | |
| 8. Near Williamson, on S. Penn. R. R., Isaac Lesher, Prop'r, | 60 | ..... | |
| Lancaster county: | | | |
| 9. At Quarryville, I. Galen Lefevre, Prop'r, | 75-80 | ..... | |
| Lebanon county: | | | |
| 10. One-half mile from Annville, Jno. A. Bachman, Prop'r, | a. 70-75<br>b. 75-80 | 36 or less. | a. soft-burned; b. hard-burned; slaked lime weighs half, or less than half as much as stone lime. |
| Lehigh county: | | | |
| 11. At Fogelsville, A. W. Held, Prop'r, | 100 | ..... | Analysis shows 90 per cent. c. l. |
| 12. Near Egypt, E. D. Boyer, Catasauqua, Prop'r, | 68-70 | ..... | Analysis shows 92 per cent. c. l., 1 per cent. c. m.; adjoins cement rock deposits. |
| Lycoming county: | | | |
| 13. On Pine Creek, near Beech Creek R. R., J. Sebring, Jersey Shore, Prop'r, | 72 | 50 | |
| Monroe county: | | | |
| 14. Boshardsville, Jno. P. Carmer, Prop'r, | 80 | 40 | |
| 15. Boshardsville, Peter M. Heller, Porp'r, | 75 | ..... | Analysis, 94 per cent. c. l., 1.5 c. m. |
| 16. Stormville, Allen Metzger, Prop'r, | 70 | ..... | |
| Montgomery county: | | | |
| 17. Whitemarsh and Plymouth Twps. G. W. H. Corson, Plymouth Meeting, Prop'r, | 70 | ..... | Screenings only sold for farm use. |
| 18. Port Kennedy, Todd & Son, Prop'rs, | 70 | ..... | Analysis, 53 c. l., 45 c. m., stone from from Chester Valley dolomite. Sell screenings only for farm use; rest for building purposes. |
| Northampton county: | | | |
| 19. 1½ miles South of Nazareth, Edw. Fehnel, Prop'r, | 80 | 50-60 | Stone is a slaty nature. |
| York county: | | | |
| 20. Hendrix Station, Western Md. R. R., Bittinger & Eberly, Hanover, Prop'rs, | 65 | ..... | Analysis, 83 per cent. c. l., 8 per cent. c. m., 4 per cent., carb. of potash. |
| Sussex Co., New Jersey: | | | |
| 21. Montague, Geo. M. Cole, Prop'r, | 80 | about 40 | |
| East Canaan, Conn.: | | | |
| 22. Canfield Bros., Prop'rs; D. T. Gates, Agt., Mansfield, Tioga Co., Pa., | 100 | ..... | The lime is shipped to Penna. In barrels. |

The wide range from 60 to 100 lbs. per bushel is thus reported for stone limes, the average for the twenty-three sorts being 76.2 lbs. There is no clearly distinguishable relation between the composition of the stone and the weight of the lime; compare, for example, Nos. 1 and 18 and Nos. 11 and 12, so that the porosity of the original stone is clearly the most influential factor, to which no doubt the conditions of burning add another potent influence.

Thus, Frasch notes that a given volume of lime from a draw-kiln weighed 55 lbs., but the same volume of lime produced from the same stone by calcination in a Hoffman flame-kiln weighed only 50 lbs.

## SLAKING OF LIME.

The general phenomena of *slaking* and its chemical nature have already been mentioned. Limes exhibit, according to the composition of the rocks from which they have been prepared and the manner in which they have been burned, differences in regard to slaking so great that they constitute the basis of the most commonly accepted classification of limes and cements.

## GILMORE'S CLASSIFICATION.

Gilmore* has given the most satisfactory classification for our present purposes. He divides limes and cements into five distinct classes, as follows:

1. Common, or fat, limes: Contain usually less than 10 per cent. of impurities. In slaking, swells to two to three and one-half times its original volume; with sufficient water, forms a homogenous paste, very soluble in water; the paste will not harden under water or under the air pump, but on standing in the air, whereby calcium carbonate and crystals of calcium hydrate are former. The paste shrinks greatly in hardening; hence, the need for addition of sand in making mortar.

2. Poor, or meagre, limes: Contain 10 to 25 per cent. of impurities, sometimes as much as 39 per cent. Slakes sluggishly, unevenly and with much less heat and swelling than fat lime. Paste less perfectly soluble. Silica is present chiefly as sand.

3. Hydraulic† limes: Seldom contain 35 per cent. impurities. Slake, but with little disengagement of heat or vapor and swelling rarely more than one-third of the original volume. They are subdivided as follows:

a. Lime slightly hydraulic; impurities, 10-20 per cent.; stiff paste, hardens under water in fifteen to twenty days.

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*Op. cit.*, p. 69 *seq.*

†By *hydraulicity* is meant the property of setting or hardening under water.

b. Hydraulic limes; impurities, 17-24 per cent.; stiff paste hardens under water in six to eight days.

c. Limes eminently hydraulic; impurities, 20-35 per cent.; paste sets under water in one to four days.

The swelling of these sub-classes is the less as they are more hydraulic in property.

4. Hydraulic cements; impurities, 36-60 per cent.; do not slake or swell with water; some set in one to four minutes at 65 degrees Fahr., others in as many hours.

Intermediate between the latter are certain clayey magnesian limestones which make good cements when underburnt, but when completely calcined, yield a paste that sets rapidly, but later cracks, softens and crumbles under water.

5. Natural puzzuolonas, chiefly composed of silica and alumina, besides other bases, but not more than 10 per cent. of calcium carbonate; these impart hydraulicity to fat lime paste even without calcination, which increases the quickness of setting but not the strength of the resulting cement.

Concerning hydraulic cements: It is generally accepted that these materials usually owe their properties to certain silicates of alumina, lime and other bases. These silicates may be formed by the action of moist lime upon natural puzznolanas (clays of volcanic origin) or upon burnt clay of other origin, or they may be formed when clayey limestones are calcined. In the last case, it is not simply the amount of clay, but also the uniform distribution through the stone that affects the quality of the cement. The action of setting in a cement is considered to be similar to that in plaster of Paris. Gypsum, the crystalline sulfate of lime, contains, combined in the crytal, nearly 21 per cent. of water; in preparing plaster of Paris, the gypsum is roasted, or "boiled," as it is technically termed, to remove this water; in this process, the crystals fall to pieces, forming a dry, white powder. When this powder is mixed with a proper proportion of water, the latter is taken up by the plaster of Paris and crystals are again formed in a short time; the soft paste has "set," or hardened. It is owing to the fact that the volume of the paste is not materially changed in the setting that plaster of Paris is so largely used in making casts or impressions.

Now, in like manner, it is believed, the anhydrous silicates formed in the cement take up, when moistened, the water necessary to crystal formation and "set," and since the crystals thus formed are little dissolved by water, the cements may be used in constructions that are exposed to the action of water.

### MAGNESIAN LIMES HYDRAULIC.

Examination by Vicat and Rogers* show that in limestones in which the carbonate of lime is substituted by 25 per cent. or upwards

*Cf. Mahan, Civil Engineering, pp. 21-23.

of magnesium carbonate (nearly corresponding to 12 per cent. of magnesia), distinct hydraulicity may appear in the presence of no more than 5 per cent. of impurities, including only 3.6 per cent. of silica and alumina. The conditions of hydraulicity in limes derived from such stone are not well understood. Frasch states that the presence of only 10 per cent. of magnesia in the stone leads to the formation of a lime that is gray and short, or of very imperfect slaking quality, and that the presence of 25 to 30 per cent. renders the lime entirely unfit for burning.

### CHEMISTRY OF SLAKING.

The *slaking of lime* requires consideration in this connection. It has already been explained that the chemical change that occurs in this process is essentially a conversion of the calcium oxid to calcium hydrate by the chemical union with water; 56 pounds of the dry oxid unite with 18 pounds of water to form 74 pounds of dry hydrate. Unlike the change that occurs when plaster of Paris or hydraulic cement sets, there is, in this case, a great development of heat, sufficient in some cases to boil water and, it appears in some cases, where the heat is prevented from rapid escape, that the temperature may rise to the point at which wood ignites. Frasch notes the observation of a temperature of 150 degrees C. (302 degrees Fahr.) in slaking lime and states that the storage of burnt lime in barrels is especially conducive to the outbreak of fire.

Whether by the formation of crystals of calcium hydrate or by the mere expansive action of the steam generated, the process of slaking pure lime is attended by large expansion. Even pure lime is subject, however, to many variations in the products of slaking, according to the conditions under which the process is performed. The mortar-maker and the plasterer are obliged to pay serious attention to these points. In this connection the few facts of chief importance in handling limes intended for agricultural use may be noted.

Limes that have advanced in slaking sufficiently to have become hot and are then chilled by sudden cooling, as by stirring or by the addition of fresh portions of cold water, will not fall to a fine powder nor form a smooth paste, but will, in considerable proportion, assume a coarse granular form. If, however, one-third of the requisite amount of water is first added, and then, just as soon as the lime has swelled to the utmost, the remainder be poured on, Frasch claims that a superior product will be obtained. The use at one time of more than the requisite amount of water also results in the formation of granular lime, as is often observed in the drowning process, commonly employed in preparing white-wash. If fresh-burned lime is piled in small heaps of three or four bushels and covered with several inches of fresh, moist soil from an upturned furrow slice, it

will take from the earth all the water needed for slaking to a fine powder. If, however, heaps of 25 to 200 bushels are to be slaked, it is well, after covering with a heavier layer of moist soil, to make small openings into the center of the mass by use of a crow-bar and to pour in water through these openings. The steam formed will perfectly slake the lime in all parts of the heap.

### WEIGHT OF SLAKED LIME.

Concerning the volume occupied by water-slaked lime, Dr. Geo. H. Cook* states that 1 bushel of good stone lime weighing 93 lbs., slakes to nearily 3 bushels, each of about 45 lbs. weight; that a bushel of oyster-shell lime weighing 60 lbs. forms somewhat over 2 bushels of slaked lime, each of about 40 lbs. weight, and that 1 bushel of magnesian lime, weighing 80 lbs., yields 2 bushels of slaked lime, each of 40 lbs. weight. It is evident, however, that the conditions of burning, purity, etc., of the lime and the conditions of slaking also greatly modify the changes in volume occurring during slaking. Thus, Gen. Totten† states, as the result of many trials that one volume of quick-lime yields, when slaked with one-third volume of water, 2.27 volumes of powder; with two-thirds volume of water, 1.74 volumes powder; with three-fourths volume of water, 1.81 volumes of powder; and with an equal volume of water, 2.06 volumes of powder.

### AIR-SLAKING.

There is another process of slaking to which attention must, in this connection, be especially directed, that of *air slacking*. When caustic lime is exposed in lump to the action of the air it gradually slakes and falls to powder as a result of the absorption of moisture from the atmosphere. At the same time with the absorption of moisture, carbonic acid is also taken up and more or less of the lime returns to its former state of combination as carbonate, though now in a finely powdered form, instead of compact as in the stone. Consequently, such lime is possessed of less causticity. Gilmore‡ says that while in a layer of ten to twelve inches thickness, some limes completely air slake in twenty to twenty-five days, others would require as many weeks and some a year. In mortar, the carbonate forms first on the outer surface and then more slowly in the interior. Vicat§ states that this layer is only .10 to .12 inches deep at the end of a year, and Reid‖ further asserts that analyses of mortars taken from buildings erected

*Loc. cit.*
†Gilmore, Lime, Hydraulic Cements, etc., p. 184.
‡*Op. cit.*, p. 183.
§Gilmore, Op. cit., p. 187.
‖*Op. cit.*

more than a century before, still show that a portion of the lime in the interior of the mortar has never been carbonated, the solidification or "setting" of the mortar being more largely due to the crystallization of the calcium hydrate than to its conversion into the solid carbonate.

Lime exposed, in small heaps in the field, to the action of heavy rains and of the air, falls to a powder more or less coarse, containing a large proportion of carbonate. Even when covered with a thin layer of earth, some carbonate is formed. In a heap of pure lime thus slaked, Voelcker* found over 15 per cent. of calcium carbonate.

H. J. Wheeler† states that dry, fine, air-slaked lime, such as has been bought from time to time by the Rhode Island Experiment Station, has been found to contain but 68 to 75 per cent. of the caustic lime (calcium oxid).

The practice of covering during slaking is much to be preferred and, where possible, that of slaking in one large heap, rather than in a number of small piles. At all events, lime should be exposed in uncovered heaps no longer than is necessary for the slaking to a fine powder, after which it should be promptly distributed and worked into the soil.

The change in volume during air-slaking is even greater than that which is caused when the lime is slaked by sprinkling. Reference to the table giving the bushel weights of fresh-burned and slaked limes produced or on sale in Pennsylvania shows that they range from 30 to 60 pounds, averaging over 40 pounds.

## TESTS FOR QUALITY OF LIMESTONE.

If it be desired to make some test of limestone to determine its quality, spalls should be taken from a freshly exposed surface of the stratum to be tested; these should be broken fine and a carefully weighed or measured portion heated with a dilute acid. The acid used may be muriatic (hydrochloric), nitric or acetic; a liberal amount of good strong vinegar may be used. The heating should be carried on in a porcelain-lined or granite-ware cup. If carbonate of magnesia be present in large proportion, the stone will not bubble or effervesce strongly upon the addition of cold acid, as it would were the stone composed chiefly of carbonate of lime with insoluble impurities only. The acid solution may be carefully poured off after heating. The insoluble residues left in the cups by different strata can then be roughly compared, and their nature as clay or sand noted.

Or, larger pieces of the stone may be burned in a coal fire; the calcined stone, better the inner portion of it, may then be treated with water to note its slaking properties, the liberation of high heat, great swelling and final formation, if the water be added in proper propor-

*Cf. Lloyd, Science of Agriculture, p. 114.
†R. I. Agr. Exp. Sta., Bull. 46, p. 109.

tion, of a fat lime-paste, all giving evidence of the purity and high value of the stone.

### COST OF LIME IN PENNSYLVANIA.

The cost of lime in different parts of Pennsylvania varies greatly, according to the distance of railroad transportation chiefly. The expense of home-burning is variously estimated: One Bedford county correspondent estimates it at 2 to 3 cents per bushel, or 4 to 5 cents per bushel, counting the cost of the labor; a Clarion county correspondent at 5 cents, labor included; a Huntingdon county correspondent at $3\frac{1}{2}$ cents, items included not being specified; a Jefferson county correspondent, at 4 cents.

Lime bought from dealers is quoted in different counties as follows:

Adams, .....6 to 11 cents per bushel.
Armstrong, .....6 to 8 cents per bushel.
Bedford, .....5 to 8 cents per bushel, as to quantity and quality.
Berks, .....6 to 10 cents per bushel.
Bucks, .....11 to 13 cents per bushel.
Butler, .....Stone, 20 cents; slaked, 8 cents per bushel.
Cambria, .....At local kilns, stone, 9 to 10 cents; slaked, 6 to 8 cents; shipped, 9 to 12 cents in carload lots.
Cameron, .....30 cents per bushel.
Carbon, .....8 cents per bushel.
Centre, .....5 to 8 cents per bushel.
Chester. .....6 cents for "fell" lime; 10 cents for small-size fresh lime.
Clinton, .....8 to 9 cents for "run of the kiln;" 10 cents, screened.
Columbia, .....6 to 8 cents per bushel.
Cumberland, .....7 cents per bushel.
Dauphin, .....6 to $7\frac{1}{2}$ cents per bushel.
Elk, .....14 to 15 cents.
Forest, .....24 cents per bushed, slaked.
Franklin, .....7 to 8 cents per bushel.
Fulton, .....8 to 10 cents per bushel.
Greene, .....4 cents at kiln.
Huntingdon, .....5 to 7 cents per bushel; slaked, 3 cents.
Indiana, .....5 to 10 cents.
Jefferson, .....6 to 7 cents.
Juniata, .....5 to 7 cents.
Lackawanna, .....10 to 12 cents.
Lancaster, .....6 to 9 cents.
Lawrence, .....10 cents.
Lebanon, .....7 cents; very pure, 9 cents.
Lehigh, .....7 to 9 cents.
Luzerne, .....6 to 10 cents.

Lycoming, .....6 to 10 cents.
McKean, .....36 to 54 cents ($10 to $15 per ton).
Mercer, .....6 to 10 cents.
Mifflin, .....6 cents.
Monroe, .....6 to 9 cents.
Montgomery, .....7 cents.
Northampton, ....6 cents for soft slate-stone lime; 7 to 8 cents for purer lime.
Northumberland, ..5 to 8 cents.
Perry, .....5 to 9 cents.
Pike, .....12½ cents.
Schuylkill, .....9 to 12 cents.
Snyder, .....7 cents; $5 per car load.
Somerset, .....6 to 9 cents.
Susquehanna, .....9 to 11 cents; $3 per ton.
Tioga, .....28 to 35 cents per bushel, or $1 per barrel.
Union, .....5 to 7 cents.
Venango, .....6 cents.
Warren, .....Stone lime, 75 cents to $1.00 per barrel; slaked, 50 cents per barrel.
Wayne, .....12 to 13 cents, delivered at railway.
Westmoreland, ...3½ to 10 cents.
York, .....9½ to 12 cents.

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## LIME IN PLANTS.

### LIME ESSENTIAL TO PLANT LIFE.

Mineral matter is absolutely necessary to the growth of plants, and every organ of the plant leaves, when it is carefully burned, a larger or smaller proportion of ashes. Among the many materials found more or less commonly in these ashes, there are several that are always present and that have been found by careful investigation to be, each of them, absolutely indispensable to the full development of all plants, being incapable of complete substitution by other ingredients. Such are lime, magnesia, potash, iron and phosphoric and sulfuric acids, and possibly soda and chlorin in very minute quantities.

### QUANTITY OF LIME IN PLANT ASHES.

Space will not permit a presentation of the composition of various plant ashes to fully show the large proportion in which lime enters

them. In the following table, compiled by Johnson,* a general statement is given of the composition of the ashes of the ordinary crops as they are at time of harvest, and will suffice to exhibit the more important differences in their lime content:

TABLE II—Composition of Ashes from Principal Classes of Crops.

| | Potash and soda. | Magnesia. | Lime. | Phosphoric acid. | Silica. | Sulfuric acid. | Chlorin. |
|---|---|---|---|---|---|---|---|
| CEREALS— | | | | | | | |
| Grain, | 30 | 12 | 3 | 46 | 2 | 2.5 | 1 |
| Straw, | 13-27 | 3 | 7 | 5 | 50-70 | 2.5 | 2 |
| LEGUMES— | | | | | | | |
| Kernel, | 44 | 7 | 5 | 35 | 1 | 4 | 2 |
| Straw, | 27-41 | 7 | 25-39 | 8 | 5 | 2-6 | 6-7 |
| ROOT CROPS— | | | | | | | |
| Roots, | 60 | 3-9 | 6-12 | 8-8 | 1-4 | 5-12 | 3-9 |
| Tops, | 37 | 3-16 | 10-35 | 3-8 | 3 | 6-13 | 5-17 |
| GRASSES— | | | | | | | |
| In flower, | 33 | 4 | 8 | 8 | 35 | 4 | 5 |

These figures show clearly that the straw is, weight for weight, richer in lime than the grain, and the tops of the root crops richer than the roots; also, that the straw of legumes, such as peas, beans and clover, is richer in lime than that of the grasses and common cereals.

## LIME REMOVED BY CROPS.

Taking into account the average amounts of ash in the various farm crops and the composition of the several ashes, using American analyses for the computation of the several averages, where they are available, the quantities of the various plant constituents that are removed from the soil by the respective crops, are as follows:

*How Crops Grow, 1890, p. 171.

TABLE II—Weights and Composition of Ordinary Crops in Pounds per Acre.

| | Weight as harvested. | Nitrogen. | Phosphoric acid. | Potash. | Lime. | Magnesia. | Iron oxid. | Sulfuric acid. | Soda. | Chlorin. | Silica. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Meadow hay (1½ tons), | 3,000 | 37.8 | 13.6 | 50.9 | 30.4 | 13.1 | 3.0 | 9.9 | 7.0 | 11.8 | 54.8 |
| Timothy hay (1½ tons), | 3,000 | 28.3 | 21.0 | 64.6 | 14.3 | 5.8 | 1.5 | 5.1 | 3.2 | 9.2 | 57.1 |
| Clover hay (2 tons), | 4,000 | 79.40 | 22.4 | 75.0 | 81.1 | 25.3 | 2.5 | 7.5 | 4.6 | 8.8 | 6.3 |
| WHEAT— | | | | | | | | | | | |
| Grain (25 bus.), | 1,500 | 28.3 | 12.4 | 8.2 | 0.9 | 3.2 | 0.3 | 0.1 | 0.6 | 0.1 | 0.5 |
| Straw, | 2,500 | 13.6 | 5.8 | 16.6 | 7.0 | 3.0 | 0.7 | 3.0 | 1.7 | 2.0 | 81.9 |
| | 4,000 | 41.9 | 18.2 | 24.8 | 7.9 | 6.2 | 1.0 | 3.1 | 2.3 | 2.1 | 82.4 |
| RYE— | | | | | | | | | | | |
| Grain (30 bus.), | 1,680 | 28.5 | 14.8 | 10.0 | 0.9 | 3.5 | 0.4 | 0.4 | 0.5 | 0.1 | 0.4 |
| Straw, | 2,000 | 9.6 | 5.4 | 18.7 | 6.8 | 2.6 | 1.6 | 3.5 | 1.4 | 1.8 | 40.8 |
| | 3,680 | 38.1 | 20.2 | 28.7 | 7.7 | 6.1 | 2.0 | 3.9 | 1.9 | 1.9 | 41.2 |
| OATS— | | | | | | | | | | | |
| Grain (50 bus.), | 1,600 | 30.2 | 11.4 | 8.0 | 1.6 | 3.2 | 0.5 | 0.8 | 0.7 | 0.4 | 17.4 |
| Straw, | 2,100 | 13.4 | 6.3 | 39.4 | 9.5 | 5.0 | 1.6 | 4.4 | 4.5 | 6.0 | 63.8 |
| | 3,700 | 43.6 | 17.7 | 47.4 | 11.1 | 8.2 | 2.1 | 5.2 | 5.2 | 6.4 | 81.2 |
| BARLEY— | | | | | | | | | | | |
| Grain (50 bus.), | 2,350 | 46.6 | 19.2 | 11.7 | 1.4 | 4.8 | 0.6 | 1.0 | 1.3 | 0.5 | 14.2 |
| Straw, | 2,800 | 13.7 | 5.4 | 29.6 | 9.2 | 3.3 | 1.4 | 4.9 | 4.5 | 4.1 | 64.9 |
| | 5,150 | 60.3 | 24.6 | 41.3 | 10.6 | 8.1 | 2.0 | 5.9 | 5.8 | 4.6 | 79.1 |
| CORN— | | | | | | | | | | | |
| Kernel (50 bus.), | 2,800 | 46.1 | 16.40 | 10.80 | 0.80 | 5.60 | 0.30 | 0.30 | 0.40 | 0.30 | 0.80 |
| Cobs, | 700 | 2.7 | 0.04 | 0.42 | 0.02 | 0.03 | 0.01 | ..... | 0.24 | ..... | ..... |
| Stover, | 2,300 | 14.0 | 8.74 | 3.82 | 11.50 | 5.98 | 3.04 | 5.75 | 1.15 | ..... | 41.17 |
| | 5,800 | 62.8 | 25.18 | 15.04 | 12.32 | 11.61 | 3.35 | 6.05 | 1.79 | 0.30 | 41.97 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| POTATOES— | | | | | | | | | | | |
| Tubers (200 bus.), | 14,000 | 47.0 | 18.9 | 67.2 | 3.0 | 5.5 | 1.2 | 7.3 | 3.3 | 3.9 | 2.3 |
| Haulm, | 4,500 | 21.1 | 6.8 | 18.8 | 28.1 | 14.2 | 2.5 | 5.4 | 2.0 | 3.7 | 6.7 |
| | 18,500 | 68.1 | 25.7 | 86.0 | 31.1 | 10.7 | 3.7 | 12.7 | 5.3 | 7.6 | 9.0 |
| SUGAR BEETS— | | | | | | | | | | | |
| Roots (20 tons), | 40,000 | 115.2 | 25.2 | 109.9 | 12.6 | 16.3 | 2.4 | 8.7 | 18.5 | 9.9 | 4.7 |
| Tops, | 20,000 | 76.0 | 23.3 | 129.0 | 99.2 | 55.6 | 2.6 | 26.0 | 67.5 | 41.6 | 49.9 |
| | 60,000 | 191.2 | 48.5 | 238.9 | 111.8 | 71.9 | 5.0 | 34.7 | 86.0 | 51.5 | 54.6 |
| MANGELS— | | | | | | | | | | | |
| Roots (25 tons), | 50,000 | 112.0 | 29.4 | 180.1 | 12.9 | 37.6 | 2.6 | 10.4 | 56.1 | 34.3 | 7.1 |
| Tops, | 18,500 | 51.8 | 16.7 | 79.1 | 27.5 | 24.6 | 3.6 | 14.5 | 50.1 | 41.2 | 9.3 |
| | 68,500 | 163.8 | 46.1 | 259.2 | 40.4 | 62.2 | 6.2 | 24.9 | 106.2 | 75.5 | 16.4 |
| TURNIPS— | | | | | | | | | | | |
| Roots (20 tons), | 40,000 | 70.4 | 38.7 | 138.2 | 32.3 | 11.2 | 2.5 | 34.0 | 29.9 | 15.4 | 5.7 |
| Tops, | 11,600 | 49.8 | 13.2 | 42.4 | 59.5 | 7.1 | 2.9 | 17.0 | 17.1 | 18.3 | 6.9 |
| | 51,600 | 120.2 | 51.9 | 180.6 | 91.8 | 18.3 | 5.4 | 51.0 | 47.0 | 33.7 | 12.6 |
| SWEDES— | | | | | | | | | | | |
| Roots (16 tons), | 32,000 | 61.4 | 18.4 | 69.0 | 21.5 | 7.4 | ..... | 39.8 | 24.8 | 7.4 | 3.4 |
| Tops, | 4,800 | 28.6 | 4.9 | 16.7 | 23.1 | 2.4 | ..... | 8.2 | 9.4 | 8.5 | 3.7 |
| | 36 800 | 90.0 | 23.3 | 85.7 | 44.6 | 9.8 | ..... | 48.0 | 34.2 | 15.9 | 7.1 |
| Cabbages (20 tons), | 40,000 | 153.6 | 48.6 | 199.2 | 95.3 | 21.6 | 3.7 | 75.2 | 52.2 | 46.1 | 4.7 |
| Onions (500 bus.), | 28,500 | 63.8 | 32.4 | 63.5 | 42.7 | 8.7 | 4.2 | 10.6 | 4.6 | 4.5 | 15.9 |
| Tobacco (leaf), | 1,500 | 58.8 | 10.8 | 67.3 | 83.4 | 17.0 | 4.5 | 14.1 | 7.4 | 15.5 | 13.4 |

## DISTRIBUTION OF LIME IN THE PLANT.

The kinds and quantities of ash constituents in any given part of the plant are not constant, but vary not only with the species and variety of the plant, and with the conditions under which it grows, but also in the same plant during its development. A number of interesting observations have been made upon the movements of lime in various plants, of which a few may be cited.

Of the various organs, the leaves are richest in lime, except in the case of trees, whose bark surpasses the leaf.

The investigations of Arendt* show 16.7 and 17.2 per cent., respectively, in the lower and upper leaves of the oat plant, while the stem contains 3.6 to 8.6 per cent., and the ears 7.3 per cent. The older leaves usually contain far more than those of less maturity. Thus, Bretschneider,† comparing the inner, or younger, leaves of the sugar beet with the outer, or older, leaves, found in the innermost only 4.7 per cent., as compared with 24.2 per cent. in the outermost. Another of many illustrations of this fact is found in the case of the chestnut. Fliche and Grandeau‡ found in leaves taken May 1, 18.41 per cent. of lime, and in others taken October 12, 49.50 per cent., while the percentage of magnesia differed little, and those of potash and phosphoric acid were greatly diminished in the older leaves.

Studying the changes that occur during the development of the grain of oats, Arendt§ obtained results indicating a transfer of lime with potash from the grain as it matures, while magnesia and phosphoric acid are transferred in large quantity from the leaves to the grain.

Lime and magnesia, which bears so much resemblance to it in its chemical reactions, are also very differently distributed in the grain of cereals, as shown by the analyses of bolted wheat flour and bran, from which it is clear that the inner portion of the endosperm from which the finer flour is prepared, contains most of the lime, while magnesia occurs chiefly in the bran. Owing to the relatively small quantity of lime in the seed, as compared with that in the leaf, it is not surprising that Boehm,|| Von Liebenberg,** Dehérain and Bréal†† have discovered that under ordinary condition of germination, lime is the first ash constituent required to be supplied from the soil in order that the processes of vegetation may be completed.

In the sprouting of the tubers of potatoes, Kellermann‡‡ found, on the other hand, that while the total ash, potash and phosphoric

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*Cf.* Johnson, How Crops Grow, 1890, p. 171.
†*Ib.* p. 172, from Hoff. Jahresbericht, **4**, 89.
‡Ann. chim. phys. (5) **8**, 500; Dehérain, Chimie Agricole, 1892, p. 156.
§*Op. cit.*, p. 237.
||Ann. Agron., I., 470.
******Ib.* **8**, 58.
††*Ib.* **9**, 127.
‡‡*Ib.* **4**, 615.

acid in the tubers steadily decreased for fourteen weeks, the quantity of lime increased five fold, being taken up from the soil and held in the old tuber in the form of calcium oxalate, the continuous secretion of oxalic acid and formation of the oxalate accounting for the absorption of the lime.

Desbarres,* in studying the development of new wood of the sumac, found little change in the composition of the ash.

### COMPOUNDS OF LIME IN PLANTS.

The condition in which it exists in the plant, varies with the species and the circumstances of its growth. When the plant is young and the lime is not present in excess, it is largely combined with the acids characteristic of the species in the form of an acid salt, present in solution in the sap. The acid malate of lime sometimes occurring so abundantly in maple sap and known to maple sugar makers under the names of "sand" and nitre," is an interesting example of this kind of compound.

### LIME SOMETIMES PRESENT IN EXCESSS.

When a soluble salt of lime with a mineral acid is taken up in excess by the plant, a portion of it may be excreted through the leaf, to be washed off by the rain, as was observed by Saussure† in the case of calcium chlorid upon the leaves of the cucumber.

Certain rather difficulty soluble compounds of lime and albuminoids are found in grains and as calcium carbonate unites with some of the group of organic substances of which starch, wood and sugar are members, it is believed by some investigators that similar chemical compounds occur within the plant.

When lime is present in large quantities, much of it is present in the form of saline encrustations or in crystals. Potato leaves often contain considerable quantities of solid calcium carbonate, which is also often found in wood and bark. In dense teak wood,‡ concretions of calcium phosphate are often found, while 80 per cent. of the dry matter of *Cactus senilis* is composed of calcium phosphate and oxalate. The leaves of the walnut, the leaf stem of the rhubarb and the beet root often afford beautiful specimens of crystalline calcium oxalate. Sachs found in the root of the young bean, crystals of calcium sulfate. The *Saxifraga crustata*, a low European plant found in lime soils, is covered by a scaly encrustation of calcium and magnesium carbonates, which Unger§ found to proceed from granular expansions on the margin of the leaf directly connected with the sap ducts; in soils poor in lime, the encrustation does not appear.

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* Dehérain, Chimie Agricole, p. 61.

†Recherches sur la Veg. p. 265; Johnson, How Crops row, p. 203.

‡*Cf.* Johnson, How Crops Grow, pp. 204, 206.

§Sitzungsber. Wien. Akad.,

Berthier* makes the interesting observation that rye, which grows well on granitic and siliceous soils, contains, in the ash from the mature straw, calcium only in the form of phosphate, while the ash of barley, which grows upon such soils only after they have been limed, contains not only as much calcium phosphate, but also a percentage of calcium carbonate much larger than that of the phosphate.

### USES OF LIME IN THE PLANT.

The functions performed in the plant by lime are not clearly defined. That it is useful in neutralization of plant acids and in their removal, when in excess in the sap, in the form of insoluble, neutral salts, has already been made apparent. Grübler† has observed the occurrence of both calcium and magnesium in the aleurone grains of seeds, where they occur as soluble, crystallizable compounds with the albuminoids, whose diffusibility they thus promote.

There is evidence to indicate that, while lime is not essential to the formation of starch in the leaf, it is useful in the normal formation of cellulose. Boehm‡ and Von Raumer§ made a series of observations upon the germination of the scarlet runner (flowering-bean, *Phaseolus multiflorus.*) Germinating it, keeping its roots in pure water and its leaves in the darkness, the young shoots are seen to develop without green color, but perfect in form, for a number of days, when, suddenly, there appears just below the terminal bud, a discoloration, and the stem wilts, withers and dies; yet the cotyleons, or seed lobes, are still unexhausted of their supply of starch, the reserve building material from which the wood of the cell walls is derived. If, however, instead of placing the roots in pure water, they be inserted in a dilute solution of any lime compound (except the chlorid), the plants maintain the stem development until the starch in the seed is completely exhausted. According to Boehm, carbonate of magnesia, instead of being able to replace lime for this purpose, is positively poisonous. Von Liebenberg|| has extended these observations with similar result to the seeds of a number of plant species.

On the other hand, Dehérain and Breal,** observed that while lime is beneficial to normal germination and indispensable to normal stem development at the ordinary temperatures of germination in the soil, the seed is able, at slightly elevated temperatures (86 degrees to 95 degrees Fahr.), to continue a healthy stem development until the starch in the seed has been exhausted, without the presence of any lime except the small amounts already present in the seed. Storer††

*Dehérain, Chimie Agricole, 158-9.
†Johnson, How Crops Grow, 1890, p. 216.
‡Jb. Ag. Chem., 1875-6, I, 255; Ann. Agron. **1**, 470.
§Vers. Stat., **29**, 251.
||Ann. Agron., **9**, 127.
**Ann. Agron., **9**, 58.
††Agricultural Chemistry, 1892, II, 407.

notes, further, the fact that cellulose formation is carried on in certain fungi, such as beer-yeast, in the entire absence of lime, the fact having been established by the researches of A. Mayer and Cohn; Storer, therefore, suggests that lime is indispensable for the proper formation of leaves, rather than for that of cellulose in general. Heinrich,* however, inclines to the opinion of Boehm, and notes the almost invariable incrustation of the cell membranes with lime compounds, an incrustation which becomes thicker as the cell grows older, especially in the case of woody cells. Loew† and Bokorny‡ regard it as playing an important part in the chlorophyll granules and of the nuclei, or reproduction centers, parts of the highest importance in the life of the plant.

### EFFECT UPON FORM OF PLANTS.

R. Heinrich§ notes that lime has a marked influence upon the external forms of vegetation; when lime is abundant in the soil, the internodes between the leaf axils are shorter and thicker, and the plants set more abundant and vigorous stalk organs and tend to heavier fruiting, whereas upon soils deficient in lime, plants shoot up in slim stalks and, though often blooming abundantly, set fruit deficiently.

E. W. Hilgard,|| speaking of the character of the growths of the several species of oaks ("post," "black jack," "scarlet" and "white") upon strong and upon light soils in Mississippi, notes that upon the former soils, the growths are sturdy, thick-set, with short, stout branches and dense tops; while on the poorer soils the growths are more slender, often very crooked and knotty, with slender branches and open or tattered top.

### CALCIPHILE AND CALCIFUGE PLANTS.

It has been noted that certain plants, such as the sugar beet and common red clover, flourish particularly well in soil containing abundance of lime; hence, such plants are called "calciphile," or lime-loving. Others, such as the sorrel (*Rumex acetellosa*), sea pine, chestnut and lupin, either grow with less luxuriance upon lime soils than upon soils deficient in this ingredient, or are injured or absolutely destroyed by liming. Such plants are called "calcifuge," or lime-avoiding. The growth of such plants as indicative of the nature of the soil and in its relation to the agricultural application of lime will be considered in another connection. It is of interest here to note that the calcifuge plants are not devoid of lime, but often contain large amounts of it. Thus, the ash analyses of the sugar beet,

*Mergel u. Mergeln, 1896, 4.
†Flora, 1892, Heft. 3.
‡Bot. Centralbl., **62**, 1.
§Mergel u Mergeln, 1896, p. 6.
|| X Census, Vol. V, 229.

compiled by Wolff, show in the ash of the root 6 per cent., and of the top 20 per cent. of lime, while those of the lupin show in the seed ash 7.5 per cent. and in that of the straw about 23 per cent.; that is, the proportion of lime in the ash of the calcifuge plant was actually the larger. If, in like manner, a comparison be made between the ashes of the chestnut and of the white oak, the latter growing especially well upon calcareous soils, it is found that the ashes of the chestnut contain, the bark 47 per cent., the wood 49 per cent. of lime, and those of the white oak, the bark 52.73 per cent., and the wood 29.85 per cent. of lime.*

Fliche and Grandeau† have made an interesting study of the composition of the sea pine. This tree prospers only on soils quite poor in lime. Analyses were made of twigs (1) taken from a tree growing on a soil containing .05 per cent. of lime in the surface, and 0.20 per cent. in the sub-soil; (2) from a tree growing in a soil containing in the surface 3.25 per cent., and in the sub-soil 24.04 per cent.; (3) for comparison, the composition of the ash of the Austrian black pine, growing well on lime soil, was determined; the percentages of lime were (1) 40.2, (2) 56.1, (3) 49.1; that is, the ash of the calcifuge plant contained about as much lime as the calciphile when both grew upon soils best adapted to their normal development. When the sea pine was grown upon a calcareous soil, its content of lime was abnormally increased, and, curiously, the percentage of potash was reduced two-thirds; the loss of vigor is probably due to the deficiency of potash. Bernard,‡ in his studies upon the vine, which, especially the native vines of France, is subject to a very destructive disease manifest through the leaves and termed "chlorosis," states that it is caused by excess of lime in the soils. When the grape leaves are examined, they appear to contain numerous crystals of calcium oxalate, and, like other calcifuge plants, show a similar tendency to throw out of circulation the excess of lime in their tissues. The juices of chlorotic grapes also appear less acid than normal and sometimes even clearly alkaline. When the chlorosis is cured, the crystals of calcium oxalate disappear.

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## LIME IN SOILS.

### COMPOUNDS OF LIME PRESENT.

In earlier paragraphs treating of the formation of limestones the fact was noted that lime is one of the rock substances more eas-

*Cf. Handbook of Exp. Station Work, 1892, p. 411.
†Ann. chim. phys., (4), 29, 383.
‡Le Calcaire, 1892.

taken into solution when rocks weather or decay. It forms somewhat readily soluble compounds with chlorin, nitric, sulfuric, carbonic acid and with certain organic acids; less soluble with other organic acids, phosphoric acid and, in certain hydrous double compounds, with silica and alumina, while its anlydrous compounds with silica are the most insoluble combinations into which it enters.

Considering the great variety of mineral substances from whose weathering and pulverization soils have been formed, with the modifying influences of the varying nature of the surface of the country and the varying extent to which living organisms have been active in the soil formation, it is not surprising that soils should exhibit a very wide difference in their content of lime.

## PROPORTION IN VARIOUS SOILS.

The following list of soils, with the proportion that they contain of lime soluble in hydrochloric acid, serves to exhibit the great differences:

TABLE IV—Percentage of Lime in Various Soils.

| Kind of Soil. | Lime. Per cent. |
|---|---|
| 1. Prairie soil from North Dakota, | .85 to 3.90 |
| 2. Virgin soil from Walla Walla; fertile, sandy, from basaltic rock, | 1.34 to 2.10 |
| 3. Muck, from Union Pier, Mich., | .97 |
| 4. Heavy prairie swamp, with clay subsoil; yields large crops of hay, fair wheat, | 1.39 |
| poor corn, | 1.28 |
| 5. Subsoil corresponding to No. 4, | .35 to 1.87 |
| 6. Drift soil, with clay subsoil, Oswego, N. Y., | .41 to 2.06 |
| 7. Alluvial bottom soil, Louisiana, | .69 |
| 8. Barren, pine-hill land. Louisiana, | .225 to .505 |
| 9. Sandy soil, Rio Grande, N. J., | .45 to .76 |
| 10. Soils from Kansas and Nebraska, prairie, | .08 |
| 11. Sugar-cane soil, Demerara, cropped 15 years, | .99 |
| 12. Sugar-cane soil, Jamaica, | 4.09 |
| 13. Rhine alluvium, Zuider Zee, Holland, highly fertile, Surface, | 5.10 |
| 15 in. deep, | 2.48 |
| 30 in. deep, | 1.23 |
| 14. Fertile wheat soil, Mid Lothian, Scotland, | .10 |
| 15. Sterile soil, Upper Palatinate, Bavaria, | .045 to .141 |
| 16. Ten sandy soils, from Alabama, Florida and Georgia, | .036 to 3.054 |
| 17. Ten clay soils from Alabama, Georgia, South Carolina, Mississippi, Tennessee and Louisiana, | .11 |
| 18. Average of 466 non-calcareous soils of humid region of the U. S. (S. C., N. C., Ark., Ky. and Gulf States), | 1.36 |
| 19. Average of 313 soils of arid region of the U. S. (Cal., Wash., Montana), | .03 to 4.50 |
| 20. Alkali soils of California, Washington and Montana, | 1.21 |
| 21. Black tschernosem, Poltava, Russia (wheat soil), | .77 |
| 22. Volcanic soil, gray, Sumatra (tobacco soil), | .07 |
| 23. Granitic soil Granville, N. C. (yellow, tobacco soil), | .61 |
| 24. Limestone soil, Donegal, Pa., | .41 |
| 25. Limestone soil, Rocky Spring, Pa., surface, | .25 |
| Limestone soil, Rocky Spring, Pa., subsoil, | |

Note.—These analyses are quoted from the following sources: Nos. 1-8, Richards, Bulletin No. 9, Chemical Division, U. S. Dept. of Agriculture: Nos. 9-12, Richardson, Special Report on the Investigation of Sorghum, 1892 (U. S. Dept. Agr.), pp. 58-64; Nos. 10-15, Johnson, How Crops Feed, pp. 362 and 366; Nos. 16-17, Hilgard, quoted by King, The Soil, pp. 84-87; Nos. 18-20, Hilgard, Bull. 3, U. S. Weather Bureau; Nos. 21-25, Frear, Rep. Pa. Ag. Exp. Station, 1894.

It is clear from these analyses that fertile soils usually contain 0.2 per cent. or upward of lime and that soils containing as little as 0.1 per cent. are usually marked for their barrenness. The texture

of the soil, since it affects the ease of extension of the plant roots, has some determining power over production; a loamy soil, through which roots readily distribute may be fairly productive with a low lime content that would cause sterility in a compact clay. On the other hand, since rain passes more readily by percolation through the former soil, it is more easily reduced by drainage to the lower limit of productiveness where the location of the soil favors leaching; sands are usually much less rich in lime than clays are.

The above illustrations do not exhibit the greatest extremes of lime percentage in soils; sea dunes often show a lower percentage, while coral sands, chalky and marly soils exhibit much higher ones; the writer has analyzed a soil from Juniata county, in this State, that contained upwards of 90 per cent. of calcium carbonate.

### LIMESTONE SOILS NOT ALWAYS RICH IN LIME.

It is a common inference that soils derived from limestone formations are necessarily rich in lime; but this is very often not the case, owing to the relative ease with which calcium carbonate dissolves in the carbonated waters of the air. Merrill* remarks that thousands of feet of such strata may disappear without leaving more than a very thin coating of soil in their place. Penrose,† from the examination of an impure limestone and its residual clay, found that the latter represented only 2.365 per cent. of the former and that, of the lime, 98.93 per cent. was lost, the rock containing 44.79 per cent., the clay 3.91 per cent. Bernard‡ cites two soils which their owners thought to be rich in lime because derived from limestone rocks, viz: From the Forest marble strata, 92.60 per cent. calcium carbonate, soil, 3.28 per cent.; Cornbrash strata, rock, 91.30 per cent., soil 0.40 per cent. Possibly the most striking illustration of this sort is that given by Spencer,§ who finds in a sandy soil on the slopes of the Alleghenies 0.14 per cent. of lime, whereas the parent limestone contains over 30 per cent.

### LIME IN COARSE AND FINE SOILS.

Some facts concerning the condition of the lime in different soils may be noted. Bernard,‖ from the examination of over one hundred soils of Jurassic origin from the district of Saone-et-Loire, France, finds equal percentages of lime in the several portions as to fineness, into which each soil was divided by sifting. In these soils, the lime is supposed to have been deposited with organic remains. But in certain soils from Cretaceous formations the percentage of lime is

*Rocks, etc., pp. 231-2.
†Annual Report Geol. Survey, Arkansas, 1890, p. 179.
‡Le Calcaire, pp. 120-130.
§Report of the Geological Survey of Georgia.
‖Le Calcaire, pp. 46-58.

much larger in the finer than in the coarser portions of the soil; Bernard believes this difference is due to a chemical precipitation of the lime in the latter soils.

### LIME IN SURFACE AND SUBSOILS.

Despite the influence of cropping and leaching, the surface soil usually contains more lime than the corresponding sub-soil. King,* taking the averages of a number of analyses of sand and clay soils finds in the sand: Surface, .115 per cent.; sub-soil, 0.096 per cent.; clay, surface, 1,761 per cent.; sub-soil, 1,481 per cent. This is doubtless due to the abundance of lime dissolved in the soil water and brought by the wick-like action of the soil to the surface, where it is left upon the evaporation of the moisture. The effect of such upward translocation is distinctly seen in comparing the soils of the humid and the arid regions, the upward movement of soluble matters being uncompensated in the latter climate by the leaching effect of rains. To the resulting abundance of lime in these soils, upland and lowland, Hilgard attributes their high and very uniform productiveness when they are irrigated.

### SOLUBILITY OF LIME.

The condition of ready solubility of lime in the soil is indicated by the fact that on examination of the results of aqueous extraction of seventeen soils discussed by Johnson,† lime was found to make up from 6 to 25 per cent. of the solid extract, being the most abundantly extracted base, constituting 20 per cent. or more of the solid extract in seven out of the seventeen cases. This is further shown by the analyses of drainage waters by Way‡ and of lysimeter waters by Zöller,§ the extracts in the former containing 10 to 25 per cent. of lime, and those of the latter 22 to 32 per cent. Magnesia was much less abundantly dissolved, and, usually, potash was more abundant when the percentage of lime was high. Moreover, Ulbricht,|| in examining the solubility of the several constituents of various soils upon repeated extraction with water, has shown that lime, more than any other constituent, maintains its readiness of solution.

The lime which is removed from the soil by water is chiefly in combination as the carbonate, sulfate, nitrate, chlorid or phosphate. Very dilute acids remove it in scarcely greater quantities than are represented by its compounds, in the soil, with the above-named acids. Much larger quantities are extractible by the use of moderately strong acids; in such cases, considerable quantities of soluble

*The Soil, p. 85.
†How Crops Feed, pp. 310-312.
‡Jour. Roy. Agri. Soc., **17**, 133; quoted by Johnson, Op. cit.; p. 313.
§Quoted by Johnson, *Op. cit.*, p. 315.
||Versuchs-Stat., **5**, 207.

silica and alumina are also liberated. It is inferred that the lime was present in combination with the silica and alumina, probably in the hydrous silicates known to mineralogists as the zeolites, which are readily decomposed by moderately strong acids with the production of soluble silica. Thus, Hilgard* notes that in the prairie soils of Alabama, Mississippi and Texas, a large percentage of lime is accompanied by high percentages of soluble silica and alumina. In some cases 1 or even 2 per cent. of lime is present, and in the mulatto clay lands of Tennessee, 6.5 to 8.4 per cent., and scarcely a trace of carbonic acid is found; in these cases, the lime is probably present as a zeolitic silicate.

### RELATION TO ORGANIC MATTER.

The relation of the lime in soils to the organic matter is one of extreme variability. In the soils analyzed by Richards (see preceding table), the proportion of lime to organic matter varied from 1:1.5, in a light, fertile basaltic soil from the State of Washington, to 1:37 in a cultivated peat from Berrien county, Mich. Infertility not infrequently occurs where the ratio of organic matter is 20 or higher. Tacke† bases his classification of moor soils upon their lime content, the characters and treatments corresponding. His classes are: (1) upland moor, 0.5 per cent. lime; (2) intermediate moor, 0.5 to 2.5 per cent. lime; (3) lower, or meadow, moor, over 2.5 per cent. lime. It is notable that despite the facts that the acids of the humus, such as the humic, ulmic, apocrenic and crenic, have the power to decompose calcium carbonate with the formation of calcium humates, ulmates, apocrenates and crenates, and that the first three of these classes of compounds are very difficultly soluble in water, the tendency of upland soils rich in organic matter is to be deficient in lime, while those of the lowlands are better and often richly supplied.

### VEGETATION TYPICAL OF NATURE OF SOIL.

As was noted in an earlier paragraph, the character of the soil, and especially its richness in lime, is often indicated by the nature of the vegetation growing upon it when in its virgin state. Thus, Hilgard‡ notes that on the long-leaf pine bottom and hummock lands of Mississippi, with 0.05 to 0.4 per cent. of lime, where water stands in the undrained sub-soil, the ink or gall-berry, wax-myrtle and similar plants prevail, but disappear as the calcareous regions on each side are approached.

Heinrich§ states that lime is certainly not lacking when the hedge-vetch, birds'-tare, chickling-vetch and red or other clovers form the natural vegetation, or when the oak, birch and locust flourish nearby, but that a deficiency of lime is to be suspected when there is a large

*X Census of the United States, 5, 81.
†Chem. Zeitung, 1895, No. 95.
‡X Census, 5, 267.
§Mergel u. Mergeln, 20-21.

quantity of sorrel (*Rumex acetellose*) or *Chrysanthemum segatum*, though no importance is to be attached to the presence of single individuals of these species for the reason that sorrel has been observed growing in marl pits, and in culture pots whose soil contained as much as 1 per cent. of lime. This author states that but few plants are really injuriously affected by lime and says that Uffelmann's supposition* that hearts-ease, quick-grass and chamomile disappear after a liming, is not credible.

A. Bernard† mentions the sand or maritime pine, the chlorotic varieties of the grape, the broom, digitalis and the chestnut as plants preferring non-calcareous soil. Speaking of the latter in particular, he urges that where the chestnut flourishes, the soil will be found poor in lime, even though the geological formation from which it is derived ordinarily yields a calcareous soil. Thus, examining the soil alone, the roots of a chestnut growing in a calcareous woodland of Ardéche, France, he found from traces up to only 0.6 per cent. of lime.

The laurel and the winter-green may be also mentioned as plants preferring non-calcareous soils.

Wheeler, Hartwell and Tucker‡ mention, as characteristic of the vegetation of certain acid upland soils of Rhode Island, birds-foot violet (*Viola pedata*, L.), wild or beard grass (*Andropogon scoparius*, Mx.), species of St. John's wort (*Hypericum*), common or soft rush (*Juncus effusus*, L.), wood rush (*Luzula campestris*, D. C.), and several mosses; while common sorrel (*Rumex acetellosa*, L.), appears as soon as cultivation is begun.

## EFFECTIVE AMOUNT OF LIME IN SOIL.

The quantities of acid-soluble lime in the soil that are requisite to bring about the above noted differences in the kind and manner of growth of plants must vary both with the texture of the soil, as noted earlier, and with the quantities of acid-forming mineral and organic substances that are present. It is not, therefore, surprising that various investigators differ in opinions derived from observations upon different sets of soils. Thus Lloyd,§ states that, with rare exceptions, soils containing 2 per cent. of lime will not require liming; that soils containing 0.5 to 2 per cent. are usually benefitted by liming, and that it is indispensable to the profitable farming of soils containing less than 0.5 per cent. of lime.

Hilgard‖ says that to manifest itself unequivocally in the tree growth, lime should not fall much below 0.1 per cent. in the lightest

*Mergel u. Mergeln, 1893, 23.
†Le Calcaire, 268.
‡Report R. I. Agr. Exp. Station, 1895, 240.
§Science of Agriculture, 1884, 111.
‖*Op. cit.*, p. 76.

sandy soil, 0.25 in clay loams, or 0.5 in heavy clays, and may advantageously rise to 1 or even 2 per cent.; beyond this, it does not affect the soil favorably except in its physical characters. This writer* has observed that on sandy lands containing 0.04 to 0.13 per cent. of lime, having a depth of eight inches of surface soil, the long-leaf pine which grows naturally upon it is, upon the application of lime, supplanted by a growth of oaks.

R. Heinrich† claims that a good soil should contain at least 0.2 to 0.3 per cent. of lime and that liming is certainly required when the proportion falls to 0.1 per cent., and, in case of a heavy soil, it is needful before the amount has been reduced to 0.1 per cent.; when 0.15 per cent. is present, liming does not lead to an increased growth of rye, oats or potatoes, and when 0.3 per cent. is present, liming or marling is without beneficial result. The same investigator, in an earlier portion of his memoir, relates the result of experiments in the culture of various plants in soils to which different proportions of lime have been added; he concludes that:

| | Lime (CaO) in soil. (Per cent.) |
|---|---|
| Lupine grow well with, | 0.03 to 0.05 |
| Potatoes and rye yield good crops, under good tillage, with as little as, | 0.05 |
| Peas and vetches die with less than, | 0.10 |
| but do quite well with this proportion. | |
| Red clover grows quite well with, | 0.1 to 0.12 |
| but dies with less than 0.1 per cent. and does best with 0.2 or more. | |

LOSS OF LIME BY CROPPING.

A number of calculations have been made to show the outgo of lime in farm products. Thus King,‡ assuming a three-course rotation of corn, clover and oats to be followed for one hundred years, each with a total product of two tons per acre per annum, the hay and straw being returned to the soil, but the grain, or its equivalent being sold, finds that the hay and straw would contain 3,102 lbs. of lime, and the grain only 86 lbs., so that with an average of 1.88 tons of lime in the surface foot of soil, this alone would supply the needed lime for over 4,000 years, were there no other loss, without the aid of the lime present in the subsoil, which is more or less drawn upon by the roots of the crops.

Or, assuming a four-course rotation of corn, oats, wheat and mixed clover and timothy, producing average crops of the quantities mentioned in an earlier table (pages 54-55), assuming that all the wheat, half the oats, one-third of the corn and one-fourth of the

*Ib. p. 264.
†Mergel u. Mergeln, p. 20.
‡The Soil, 102-104.

hay were sold, the remainder of the crops being fed upon the farm; that one cow were kept for each two acres under cultivation, yielding 7,000 lbs. of milk sold off the farm each year and that for each cow there were bought 750 lbs. of cotton-seed meal and 1,500 lbs. of bran each year, the outgo would be, for each acre:

| | Lime (Lbs.) | |
|---|---|---|
| In wheat (6¼ bushels), | 0.22 | |
| In oats (6¼ bushels), | 0.20 | |
| In corn (4 1-6 bushels), | 0.07 | |
| In hay (220 lbs.), | 2.98 | |
| In milk (3,500 lbs., at 2 lbs. of lime per 1,000 lbs. milk), | 7.00 | |
| | | 10.47 |
| The income would be: | | |
| In 375 lbs. cotton-seed meal, | 0.68 | |
| In 750 lbs. wheat bran, | 1.27 | |
| | | 2.95 |
| Net annual outgo by cropping, | | 7.52 |

LIME ADDED IN FERTILIZERS.

On the other hand, the manurial substances brought upon the farm for the purpose of supplying nitrogen, phosphoric acid, potash and other substances commonly contain also considerable quantities of lime.

Thus, in a ton of the following substances lime is contained in the quantities and states of combination indicated:

TABLE V—Amounts of Lime in Various Fertilizers.

| Substance. | Lime compound. | Pounds of lime. |
|---|---|---|
| Ashes (lime kiln), | Caustic lime and carbonate, | 970 |
| Ashes, wood, leached, | Carbonate and phosphate, | 560 |
| Ashes, wood, unleached, | Carbonate and phosphate, | 680 |
| Bone ash, | Phosphate, | 900 |
| Bone meal, | Phosphate, | 540 |
| Cottonseed hull ashes, | Carbonate and phosphate, | 100 |
| Gas lime, | Carbonate and sulfate, | 880 |
| Kainit, | Chlorid and sulfate, | 23 |
| Kieserit, | Chlorid and sulfate, | 56 |
| Marls, | Carbonate and phosphate, | 0-900 |
| Land plaster, Cayuga, | Sulfate and carbonate, | 800-850 |
| Land plaster, Nova Scotia, | Sulfate and carbonate, | 820 |
| South Carolina rock, ground, | Phosphate and carbonate, | 840 |
| South Carolina rock, dissolved, | Phosphate and sulfate, | 420(about) |
| Tannery ashes, | Carbonate and phosphate, | 680 |
| Tobacco stalks, | Nitrate, malate, etc., | 44 |
| Tobacco stems, | Nitrate, malate, etc., | 84 |
| Thomas slag phosphate, | Phosphate and oxid, | 970 |

With every pound of phosphoric acid applied in the ordinary forms of commercial fertilizer, the presence of at least 1¼ lbs. of lime is assured.

From these facts it is clear that in an application of 200 lbs. of dissolved South Carolina rock, fully 40 lbs. of lime is added to the soil, an amount several times greater than that removed in a single year by the crops sold off from the acre.

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## INFLUENCES OF LIMING UPON SOILS AND THE VALUE OF MAGNESIAN LIMES

Having noted the quantities and conditions in which lime occurs naturally in the soil, and the ways in which it is lost or increased by the processes of cropping and chemical manuring, it remains to consider the changes wrought in the soil by the application of lime.

### CLASSES OF EFFECTS OF LIMING.

Numerous observations and investigations have shown that the direct and indirect results of liming are quite numerous and complex, instead of being few and simple. The various results may, however, be grouped as those which affect:

A. The mechanical condition of the soil;

B. Its chemical composition particularly as regards

1. The kind and proportion of available plant food it contains.
2. The presence of substances injurious to plant life.

C. The biological characters of the soil; i. e., the nature and vigor of the organisms living in it and of the plants growing upon it.

These different effects of liming will be discussed in the following paragraphs, free use being made of the numerous observations and experiments made elsewhere upon the subject; but the effects of lime upon a number of Pennsylvania soils that have shown in practice very marked benefits from liming, will be presented so far as they are indicated by the results of careful laboratory investigations made by the writer, with the aid of his assistants in the Chemical Laboratory of The Pennsylvania State College Experiment Station.

### SUPPOSED INJURIOUS EFFECTS FROM MAGNESIAN LIMES.

It was thought desirable to study, at the same time, the effect of caustic magnesia upon these soils, for the reasons that a very large proportion of Pennsylvania limes are magnesian and that the general opinion of agricultural writers has been that highly magnesian limes may not only be of little use, but may even prove positively injurious

to the crops. Thus, Lloyd* states that lime is the only material of value in burnt lime and applies the adjective "bad" to a lime containing 60 per cent. of lime and 30 per cent. of magnesia. Low† says of the magnesian limestone of England: "If applied, after being calcined, in the same quantity as other limes, it produces a temporary sterility, burning, as it were, the soil; hence, it is termed hot lime and is applied in much smaller quantity than other kinds of lime." This action he attributes, after Sir Humphrey Davy, to the longer period of causticity commonly supposed to occur with magnesia. In the form of carbonate, he says, "magnesia seems to exercise a highly favorable action; and magnesian limestone may perhaps be regarded as the most valuable of any, since a smaller quantity of it suffices for the ends proposed. No other limestone is so efficient in the case of peaty soils, and it is probable that the superiority observed in the case of the limestone of the coal formation over that of the pure chalk is due to the presence of this earth."

Prof. Geo. H. Cook,‡ late geologist of the State of New Jersey, and Director of the New Jersey Experiment Stations, says, in speaking of limes: "It is doubtful whether magnesia has any fertilizing properties, and it is thought by many that it is a loss to buy and handle magnesian limes."

P. P. Dehérain,§ speaking of hydraulic limes in general rather than of magnesian limes simply, says they will, if spread upon the soil without previous complete exposure to the air, form a hard layer upon the soil during the first rain and become injurious rather than useful.

J. Boehm's|| observation that carbonate of magnesia is unable to take the place of lime in promoting healthy germination but is, instead, positively poisonous, has already been noted.

R. Heinrich,** having observed injury resulting from the effect of calcium carbonate upon the growth of the lupin, states that magnesium carbonate is far more injurious, the presence of 0.5 being sufficient to entirely prevent the growth of the plant. The same writer†† says: "It is suspected that applied in considerable quantity, so that, especially, the magnesia exceeds the amount of lime in the soil, it is as deadly to some plants as lime carbonate is to lupins. Different plants show different sensitiveness to the magnesia content of the soil. Most dolomitic rocks contain far more lime than magnesia; no immediate injury, therefore, results from their use, but because lime is more freely dissolved out of the surface soil than magnesia is, the injurious effect may be seen later when the magnesia

*Science of Agriculture, 113.
†Practical Agriculture (4th ed., 1843), 88.
‡N. J. Agr. Exp. Station, 2d Ann Rep., 31.
§Chimie agricole, 520.
||Ann. agronomiques, **1**, 470.
**Mergel u Mergeln, 63.
††*Ib.* p. 31.

comes to be in excess. The injury from caustic magnesia is clearly established, but further investigation is needed regarding the effect of the carbonate."

The subject is quite fully discussed by Storer,* who notes that it was early observed by English chemists that certain limestones which had sometimes been found in practice to injure crops, contained magnesia, and that Tennant, on applying calcined magnesia to various soils with different crops, found that his plants either died, were unhealthy or vegetated very imperfectly; also, that Knop found, in growing plants by water culture (i. e., in very dilute solutions of plant foods), that magnesium salts are distinctly harmful unless accompanied by abundance of lime, potash or ammonia salts; by themselves, the magnesium salts caused peculiar malformations of the plant roots, followed shortly by the death of the plants.

Storer notes, on the other hand, that Sir Humphry Davy found that the very magnesian limestones to which objection was made, gave very beneficial results on certain soils and that magnesia, though injurious when present in caustic condition in considerable quantity in ordinary soils, may be beneficial when mixed with peat or when present as carbonate. He also notes Stöckhardt found, in the limestones producing the best results and most enduring upon the lowlands of Saxony, as much as 40 per cent. of magnesia. The suggestion is made that the readier solubility of magnesium carbonte in the carbonated soil-water may give magnesian limes real superiority over pure limes as ameliorants of heavy land.

Viala and Ravaz† have observed that dolomitic soils are not nearly as injurious in the production of chlorosis of the vine as are more purely calcareous lands. Bernard suggests that this is due to the somewhat greater resistance to decomposition offered by magnesium carbonate.

O. Kellner‡ urges that Magnesia is useful and poisoning of the plant by it is the result simply of using it in too large quantities.

### FUNCTIONS OF MAGNESIUM IN PLANTS.

In support of this opinion it may be summarily noted in this connection, as established by numerous experiments by the methods of water-culture and of sand-culture, that magnesium is absolutely indispensable to the growth of plants to full maturity. While all its functions in the plant are not known, it is certainly able to neutralize acids as lime does, though it does not form crystallizable compounds so easily thrown out of circulation as calcium carbonate or calcium oxalate. Like lime, it is present in aleurone grains with albuminoid

*Agriculture, 4th ed., 1897, II, 135-7.
†Bernard, Le Calcaire, 63.
‡American Fertilizer, 6, 245.

materials and forms alkaline phosphates which may aid in the movement of albuminoids from one part of the plant to another. Its most clearly established function, however, is its necessary connection with the formation of chlorophyll, the green coloring matter through whose agency, under the action of sunlight, the plant is enable to fix the carbonic acid of the air in its leaves in the form of sugar, starch or oil. Von Raumer* found that in the scarlet runner, when deprived of magnesium, the uppermost joints soon ceased to lengthen, became exceptionally thick and hard and showed only the faintest green tint, the color being almost white. Hoppe-Seyler† found in the pure crystallized chlorophyllan obtained from grass, 0.34 per cent. of magnesia; and chlorophyllan appears to be closely related to the ordinary chlorophyll.

### USE OF MAGNESIUM SULFATE AS A FERTILIZER.

A second fact in support of this opinion is the good result occasionally attending the use as a fertilizer of magnesium sulfate (Epsom salts) in the form of the Stassfurt salts, kieserit and krugit.

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## PENNSYLVANIA EXPERIMENTS.

### SOILS EXPERIMENTED UPON.

The soils used in the experiments hereafter described were carefully selected to represent a large variety of the soils for which a large return from liming was claimed by various correspondents. The source, nature, response to liming and method of sampling of the several soils are stated below.

I. *Ironstone soil*, from the Spring-and-Meadow Farm, Washington Township, York County, sampled by Mr. L. W. Lighty, East Berlin, Adams County, Pa. This soil formation lies between strips of blue shale, outside of which are found red shale and red sandstone; the ironstone soil is about three-fourths of a mile wide and extends from the Susquehanna opposite Marietta, bearing south of west, passing south of Gettysburg. The soil is uneven in formation; 10 per cent. of it is a whitish clay of very fine texture, runny when wet, but powdery, not cloddy, when dry; 5 per cent. is a tough, heavy, cold clay, mixed with a small proportion of coarse sand; this soil dries very slowly and bakes to clods; 5 per cent. is pure, rather coarse sand mixed with flint and granite, but 80 per cent. is a very fine sand, mixed with less clay, and it becomes sticky and smeary when wet and dries slowly; when handled properly in a dry condition, it works very nicely; washes and gullies when on an exposed slope. In general, the soil is a fine, grayish-yellow sand. It is very deep, sometimes as much as

*Versuchs-Stationen, **20**, 263-273.
†Quoted by Johnson, How Crops Grow (1890), 125.

forty feet. Soil taken from far below the surface and spread upon the ground, supports at once a very rank, vigorous vegetation, and is rarely bare, weeds and briers growing rapidly in the absence of crops. The soil bears drought very well, and is a hard, rough soil, but responds well to treatment. All crops and trees grow well upon it.

The sample was taken from a tract of four acres, having a surface soil one foot deep, with a sub-soil similar, but sharper and full of boulders. The tract was rolling upland, rather damp, had been long under cultivation in a rotation of corn, wheat and clover; its production is about 15 bushels of wheat and 60 bushels of ear corn; its plow depth is about 10 inches. Liming alone is not so noticeably useful as its application in connection with clover sod or manure. The soil is naturally well supplied with humus and rarely becomes deficient therein. When lime is applied to this soil, 20 to 50 bushels makes no easily apparent change in its condition; if more than 50 bushels be added, the soil becomes mortar-like and hard to handle. After liming, the retentiveness for moisture appears to be increased. The particular tract sampled had not been limed for at least forty years, and was in corn-stubble when the sample was taken; sub-samples were taken of the surface soil at twelve different points, carefully mixed by shoveling over and passed through a one-half inch screen; 3 per cent., consisting of roots and small stones, failed to pass the screen. The combined samples amounted to several barrelfuls.

II. *Black slate soil*, from Hopewell Township, Cumberland County, Pa., about five miles north of Shippensburg; sampled by Hon. S. M. Wherry, of Shippensburg. This soil is light, easily tilled, easily affected by drought, but yielding well in wet seasons; liable to wash. The soil grows hickory, all kinds of oaks, some pines, fall-grass, ragweed and all forms of briars, and is especially good for wheat. The surface soil is about twelve inches deep, although the plow-depth is commonly only six to eight inches. The sub-soil is hard, black slate or red shale. Lime seems more beneficial upon this than upon most soils in the locality. The tract of ten acres from which the sample was taken had never been limed, but was an old soil under a rotation of corn, oats, wheat and grass. Sub-samples were taken from eight points in the tract, to a total weight of 1,000 to 1,200 pounds; after careful mixing the soil was screened and about one-half of the entire amount—composed of sod, roots and large pieces of slate—failed to pass a half-inch mesh screen.

III. *Red shale* from Lykens Valley, Dauphin County, Pa., sampled by Mr. John Moyer, Gratz, Pa. This soil is a dry, sloping upland, with surface soil of fourteen to twenty inches, and a plow-depth of six or seven inches, and with a red gravel sub-soil. The soil tends to bake and solidfy on drying so as to greatly injure any crop growing upon the land. The golden rod and plantain are the most conspicu-

ous weeds, and wheat grows better than other crops, but the soil is not naturally strong; the fertility after the use of lime, with manure, is greatly improved, and the soil is kept much lighter and more porous. The twenty-acre tract from which the sample was taken had not been limed for at least twenty years, and, before that, only infrequently and at a rate of not more than fifty bushels per acre. The land had been under cultivation for a long time, and when sampled was in corn; ten sub-samples were taken at different points to a total amount of four bushels; these were well mixed and put through a one-fourth inch screen; stones and roots to the amount of one-fourth of the original soil were separated.

*IV. Limestone clay* from the eastern slope of the limestone strata running through Morrison's Cove, in South Waverly Township, Bedford County, one mile from Loysburg Gap; sampled by Mr. J. S. Biddle, of Loysburg, Pa. The soil is a very heavy "limestone" clay, which cannot be worked wet and bakes on drying. Rag-weed, the wild cherry and apple and clover grow vigorously and corn does very well. The soil is about six to eight inches deep, and the sub-soil is heavy clay several feet deep. Lime loosens it. The tract of two acres from which the sample was taken was dry, sloping upland that had been under cultivation for over fifty years and had never been limed; sub-samples were taken at twelve places and the mixed soil passed through a one-quarter inch screen, through which one-third of the weight refused to pass, composed of stone, roots, etc.

*V. Glacial loam* from Scrubgrass Township, Venango County, sampled by Mr. Ed. Anderson, of Big Bend, Pa. This soil is loose, with a gravelly sub-soil, containing a little clay; wet weather does not injuriously affect it. The prevailing forest growth is chestnut, and produces about fifteen bushels of wheat to the acre. The sample was taken from an upland tract of twenty-five acres, part upland level, part slope; sub-samples were taken at six points to a total weight of 1,000 pounds. Of this, one-third, composed of small stone, grass roots, etc., failed to pass a one-quarter inch screen. This land had been in wheat four years before and in grass since then; the soil was old and had never been limed.

*VI. Muck* soil from the "sand barrens" of Centre County, a narrow strip one-half to several miles in width, extending for twenty-five to thirty miles through Nittany Valley, and containing many small hollows, more or less filled with muck and sandy wash. The sample was taken at a spot about two and one-half miles from the State College, by Mr. W. S. Sweetser, Assistant Chemist of the Experiment Station; the hollow from which it was taken was 150 to 200 square feet in area, with a surface of much five to six inches deep, and with a sub-soil of almost pure sand. The vegetation upon the surrounding tract was of pine, chestnut and oak. The soil was virgin, of course, and ten samples, amounting to about a barrel, were taken. Of this,

one-tenth only was too coarse to pass a one-quarter inch mesh, the coarse material being composed solely of sticks and roots.

*VII. Limestone clay* soil from Nittany Valley, Centre County, on the farm of Mr. A. Markle, State College, Pa., representing well the large soil areas forming the floor of central Pennsylvania valleys, the soil being formed from the Lower Silurian rocks. This soil often responds very well to liming, the texture being made more porous, and crop yields considerably higher. The characteristic tree is the oak, and rag-weed the most abundant mid-summer weed. The sample was taken by Mr. W. S. Sweetser, from a field of one acre area that had never been limed; it was in corn at the time, forming part of the ordinary four-course rotation. The situation was upland, the soil well drained naturally, with surface soil of ten inches depth, and a usual plow-depth of seven to eight inches. The sub-samples were taken from eleven points to the amount of a barrel. Of this, 4 per cent. only, composed of small stones with a few roots, was too coarse to pass a one-quarter inch mesh.

VIII. From the farm of Mr. Mitchell Bachle, Blanchard, Pa., *Creek bottom loam*, sampled by Mr. C. W. Norris, Assistant Chemist of the Experiment Station. Soil was of rather light, sandy texture, and of light color; the surface of the ground sloped a little toward the southeast, but was otherwise quite level. The land was cropped with clover, had been long cultivated and never limed, nor has it been manured for seven or eight years. The plow depth is 10 inches. Land responds well to liming. The tract sampled lay near the creek, was of two acres area, and was sampled in 10 places. Of the combined sub-samples, little more than 2 per cent., consisting of small stones and roots, failed to pass a screen of one-quarter inch mesh.

*IX. Red shale* soil from the farm of Mr. David Mapes, about two miles west of Beech Creek, Clinton County. The soil is especially productive of clover and the plaintain was the most conspicuous weed upon the tract sampled. The effect of liming is to loosen the soil and greatly improve the yield. The tract was sloping upland, dry, with a surface soil ten inches deep, and a hard red-shale sub-soil; the plow-depth was eight inches. The field had been in cultivation for twenty years in the ordinary four-course rotation and is not known to have been limed. Over an area of two to three acres, sub-samples were taken at thirteen places to the amount of 700 pounds. Of this, 27 per cent., composed of small, flat stones, failed to pass a one-quarter inch mesh.

### CHEMICAL ANALYSIS.

Of each of the samples thus collected, a large portion was carefully air-dried in a drying-closet, the sample allowed to remain exposed for some time to the air of the laboratory and then carefully sifted through a one-half millimeter seive to remove gravel, roots, etc. Of

these various samples the following proportions were able to pass the seive, the figures for Samples VI and VII having failed to be preserved:

| | Per cent. |
|---|---|
| I, | 78.4 |
| II, | 50.0 |
| III, | 75.1 |
| IV, | 77.1 |
| V, | 88.6 |
| VIII, | 89.7 |
| IX, | 79.1 |

In preparing a solution of these soils for the purpose of determining in part the materials capable of solution in hydrochloric acid of 1.115 specific gravity—the solvent customarily employed in soil analyses and supposed to indicate the kind and amount of material capable of being taken up by plants sooner or later as the land is cropped—the following method was used: Ten grammes of the air-dry soil were introduced into a small flask, 100 c. c. of the acid added, the flask connected with a reflux condenser and digested for ten hours on a water-bath at the temperature of boiling water. The flask was cooled, the liquid filtered off from the undissolved residue, the filtrate evaporated to dryness. The soluble silica present in the original acid solution having been thus rendered insoluble, the other substances were redissolved in a few drops of hydrochloric acid and hot water and the solution filtered. The filtrate was made up to 500 c. c., and various portions of it used for determining several of the soil constituents by the official methods of the Association of Official Agricultural Chemists of the United States.

### LIME AND MAGNESIUM CARBONATES IN THE SOILS.

In the following table are given the percentages of hygroscopic moisture, lime, magnesia and carbonic acid present in the several soils; also, the proportions of the lime present in the form of carbonate; these determinations were made by Mr. C. W. Norris, Assistant Chemist; in no case was the carbonic acid liberated on warming the soil with dilute acid, sufficient to combine with all the lime present, much less with the magnesia also.

TABLE VI—Lime, Magnesia and Carbonic Acid in Soils. (Per Cent.)

| Soil. | Hygroscopic moisture. | Lime. | Magnesia. | Carbonic acid. | Proportion of lime combined as carbonate. |
|---|---|---|---|---|---|
| I, | 2.37 | 0.83 | 0.75 | 0.034 | 5.1 |
| II, | 2.00 | 0.24 | 0.71 | 0.039 | 20.4 |
| III, | 1.39 | 0.25 | 0.43 | 0.035 | 17.6 |
| IV, | 1.64 | 0.29 | 0.44 | 0.044 | 19.0 |
| V, | 1.96 | 0.08 | 0.19 | 0.025 | 38.8 |
| VI, | 4.85 | 0.11 | 0.10 | 0.046 | 53.6 |
| VII, | 1.36 | 0.26 | 0.35 | 0.039 | 19.2 |
| VIII, | 1.49 | 0.29 | 0.45 | 0.030 | 13.3 |
| IX, | 1.73 | 0.28 | 0.69 | 0.048 | 21.8 |

The variations in hygroscopic moisture are evidently too slight to introduce any material error in conclusions drawn from a direct comparison of the foregoing figures.

It is interesting to observe that only in the case of the glacial loam, No. V, and of the muck soil, No. VI, are the proportions of lime less than 0.2 per cent., the amount considered sufficient for the food supply of agricultural plants. Yet, except in case of the ironstone soil, the proportions are not far above this requisite proportion.

In every instance except those of No. I and No. VI, the ironstone and muck soils respectively, the percentage of magnesia in the soil is appreciably greater than that of lime; and in the exceptional soils indicated the lime is barely more than equal to the magnesia.

Except in the muck soil, only a small part of the alkaline earths are present as carbonates;* in most instances, not more than 20 per cent. of the lime is so combined, and in the ironstone soil only 5 per cent. Doubtless a very considerable part of that dissolved is present in the soils in the form of silicates.

### RATIO OF LIME TO MAGNESIA.

Concerning the proportions which the magnesia bears to the lime in these soils, it may be further remarked that the excess of magnesia here observed is not at all unusual; the mean percentage of lime in 466 non-calcareous soils from humid regions that were analyzed by Hilgard, was 0.108 per cent., while that of magnesia was 0.225 per cent.; in 313 soils from arid regions, the average lime content was 1.362 per cent.; that of magnesia, 1.411 per cent.

*Much care was used in determining the carbonic acid: 20 grammes of the fine, air-dry soil was introduced into a small flask, covered with freshly boiled water and thoroughly moistened by agitation. The flask was then connected with such absorption apparatus that the air entering the flask is free from carbonic acid, while any of this gas liberated from the soil is absorbed, after the air has been dried, in a special weighed portion of the apparatus, from whose increased weight the quantity of carbonic acid is ascertained. 40 c.c. of concentrated hydrochloric acid was then introduced into the flask, its contents heated to boiling and the air drawn through the apparatus for 15 minutes as the flask cooled.

In view of these facts, it is unsafe to conclude that an excess of magnesia soluble in hydrochloric acid of 1.115 specific gravity is indicative of a condition of the soil whereby pronounced injury must result to crops growing upon it. It is more probable that the supposed injurious action must be attributed to the presence in excess of some particular magnesian compound or compounds, rather than of magnesian compounds in general.

The mere fact that the composition of large agricultural areas represented by the above analyses shows an average preponderance of magnesia over lime, does not, of course, preclude the possibility that a reverse relation of the acid soluble portion of these two soil components might prove more advantageous to plants grown under the artificial conditions of agriculture. There is, however, no warrant in existing knowledge upon the subject for concluding that any part of the benefits observed to result from the application of lime to the several soils experimented upon, arises from a change in the ratio between the magnesia and lime present. It is noteworthy, however, that where the differences in percentage between the two are only slight, no unusual application of lime would be required to overcome it; thus, for each 0.1 per cent. of excess of magnesia over lime, an application of little more than a ton of pure lime per acre would equalize the amounts of these substances in the surface soil taken to a depth of eight inches; whereas, applications of ten tons to the acre are not very infrequent.

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## Physical and Chemical Effects of Applications of Lime and Magnesia.

### DETAILED PLAN OF EXPERIMENT.

Owing to the difficulty of detecting by analysis minor changes in the composition of soils, a maximum application was determined upon. Two hundred bushels of the heavier stone lime would weigh about 18,000 lbs.; assuming the dry surface soil to weigh 3,600,000 lbs. per acre, taken to the depth of a foot, such an application would correspond to 1 lb. of lime to each 200 lbs. of soil. As the mechanical mixture of the soil and lime is not perfect under the usual conditions of liming, it doubtless happens quite often that the immediate influence of the lime applied is limited to a zone of three or four inches depth. Under laboratory conditions, the admixture is much more perfect, so that the above proportion need not be considered as excessive in such degree as to impair the value of any results obtained.

Both the lime and magnesia were chemically pure, and perfectly caustic; only freshly ignited materials, cooled under conditions that precluded air-slaking, were used.

As it was considered probable that the chief effects would be those resulting from chemical reactions produced by the lime and magnesia respectively, the latter was not employed in quantity equal to the lime, but in such amount as would be chemically equivalent to it, viz: 40 parts of magnesia to 56 parts of lime.

The quantity of soil used was 2,000 grammes.

Three treatments were given to as many portions of the several soils.

A. Preservation in a moist condition without any admixture.

B. Mixture with 10 grammes of lime, and preservation in a moist condition.

C. Mixture with 7.14 grammes of magnesia, and preservation in a moist condition.

The lime and magnesia were thoroughly mixed with the soils, both being in dry condition.

The dry soils subjected to the several treatments were then introduced into large bottles, so covered as to protect their contents from the ready entrance of dust, insects, etc., but without preventing a constant change of the air in the bottles. The soils were then carefully moistened without stirring, placed in a basement room and kept there for ten months. During the first three months water was added in small quantities, to maintain a uniform condition of moistness so far as the eye could determine. At the close of the ten-month period, the soils were air-dried, again sifted through a one-half mm. seive, as at first, and preserved in sealed jars pending analysis.

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## Mechanical Effects of Liming.

### INFLUENCE UPON CLAY SOILS TO INCREASE POROSITY.

It is a matter of almost universal comment that the application of lime to a "runny" or heavy clay results in a marked increase in the porosity, lightness and crumbly character which are essential to a soil fit for the highest tillage. Indeed, so marked is the influence of lime upon such soils that, in some localities, it is asserted that only upon heavy clay land is lime ever beneficial. To reach an understanding of this effect of lime, it is needful to consider the essential differences between the heavy clay and the lighter soils. The terms "heavy" and "light," as used in this connection, do not refer to weight, because a cubic foot of dry sand weighs about 110 lbs., while a cubic foot of clay, taken from "heavy" land, often weighs only about 80 lbs. Reference is had instead to the draught required for their tillage, the adhesiveness and strong coherence of the clays, greatly increasing the power necessary to draw the plow through them as contrasted with sandy soils.

These differences are due chiefly to the texture of the soil or, in other words, to its mechanical structure. All soils are composed of more or less finely sub-divided minerals resulting from the weathering of the rock from which the soils were derived, with more or less "humus," or decayed vegetable matter admixed. A separation of the fine and coarse particles in various soils shows them to be vastly different in the proportions of the particles of various diameters which they contain. The following data obtained by Whitney,* in examination of the coarse "pine barrens" and heavy Helderberg limestone clay soils of Maryland, will serve to illustrate the mechanical differences between the two types of soil (all material coarser than two mm. having been first removed by sifting):

| | Pine barrens soil. | Helderberg limestone soil. |
|---|---|---|
| Number of grains per gramme of soil (millions), | 1,692 | 19,638 |
| Surface area of the particles in 1 gramme of soil (in centimeters), | 496 | 4,575 |
| Empty space in the dry soils (per cent.), | 40 | 65 |
| Water content when saturated (per cent.), | 20.1 | 41.2 |

It is clear, therefore, that the number of grains in a given weight of clay soil is very much greater than in the same amount of a sandy soil, and, consequently, that the average diameters of the clay particles must be much less than those of the sand grains. It is further clear that, since the density of the minerals composing sand and clay are much the same, a dry clay soil weighing less than a sandy one, the arrangement of particles in the clay must be such as to leave more empty space, and direct examinations of the soils in the field show this to be true. A clay soil will, when saturated, hold more water than a sand. Owing to the fineness of pores in a clay soil, water will be lifted higher in it by capillary action, will be pulled out of or through it more slowly by the influence of gravity and, when the soil is dry, will distribute more slowly through it. It is, therefore, characteristic of clay soils to be more moist than sandy soils in damp weather, to dry more slowly in spring time, to swell on becoming moist after a dry season, to heave on freezing by expansion of the water contained and to bake into a hard mass on drying. In such compact soils, the roots of plants penetrate with difficulty, the roots

*U. S. Weather Bureau, Bull. 4.

are broken by the heaving during the winter's frost and plants suffer from excessive wetness and coolness of the soil in spring time and from excessive droughts in summer.

Furthermore, if such soils are trampled, pressed by the plow share or kneaded in any way, the arrangement of the particles is changed and the clay is said to be "puddled." In such condition water, even under high pressure, scarcely passes through it; upon drying, it bakes in the form of hard clods; it is readily gullied by running water, making the streams highly muddy. The tillage of such land requires the greatest care.

The plasticity that is characteristic of clay soils is by some attributed to a gummy, or "colloidal," cementing substance, probably a silicate of alumina; by others it is urged that the very fineness of the particles is in itself sufficient to account for this quality. There is some evidence that both are in part correct.

## FLOCULATION OF CLAYS.

When the extremely fine silt or mud from certain clays is suspended in rain water, it often settles out only very slowly. Prof. Wm. H. Brewer, of Yale University, in a private communication, informed the writer that a sample taken by him from the muddy waters of the Missouri river and placed on a shelf, where it was free from agitation, failed to settle clear even after six months had elapsed.

If, however, certain saline solutions are admixed with the muddy water, the precipitation of the silt is greatly hastened. This is accounted for upon the supposition that several of the fine particles are made under the influence of these solutions, to cohere, in light flocks, whereby their surface is diminished and they settle out from the liquid more readily. Thus, when the muddy waters of the Mississippi encounter the waters of the Gulf, the salts in the latter bring about the "flocculation," as this change in condition is termed, and the silt deposits to form the great delta which is ever pushing out into the Gulf.

On examining the flocculating power of various substances, Schlösing* found that quick-lime and the various salts of lime were the most active flocculants, magnesium salts nearly as effective, potassium salts weaker and the salts of sodium and ammonium still weaker. In some cases, two parts of lime in the form of chlorid, nitrate or sulfate, caused immediate flocculation in 10,000 parts of turbid, clayey liquid.

Hilgard has repeated Schlösing's experiments with like results.

The action of these flocculants upon a "runny" clay soil likewise results in its granulation or flocculation. If, however, the flocculant

*Cf.* Storer, Agriculture, 4th ed., Vol. II, p. 144.

be removed by leaching, the "runny" character of the clay reappears. To show this action, Hilgard suggests the following experiment: Work a portion of tough clay into a plastic mass with soft water; on the one hand, mix one part of caustic lime with 200 of the clay before working into a paste with water; on drying the former portion becomes of almost stony hardness, the latter crumbles readily at the touch.

### THEORIES OF FLOCCULATION.

The cause of this action is not fully understood. Schlösing found that in washing the soluble materials from soils by water, silt was held back when a current of carbonic acid gas was passed through the soil during the washing; from this fact it has been inferred that the acid carbonate of lime is the active flocculant. Hilgard* also observed that the destruction of the causticity of the lime in a magma of limed clay by causing a stream of carbonic acid to bubble through it for twenty-four hours, did not at all restore the plasticity of the clay; hence, the flocculation does not necessarily require caustic lime. But the action of the neutral carbonate is much weaker.

Hilgard, Brewer and Barus,† proceeding upon the theory that the clay particles are, in part at least, in a gummy or colloidal condition, suggest that flocculation results from a dehydration of the clay under the action of the saline solutions. Whitney urges, however, that such an assumption is needless since the facts may be accounted for by the laws of surface tension; for, assuming two grains of clay to lie in contact with each other on the surface of a liquid, if the attraction of the liquid for the surfaces of the clay is greater than the attraction between the different portions of the liquid, the latter will rise between the particles and tend to separate them; if, on the other hand, the reverse is true, the clay particles would, when separated, tend to come together. The determinations made by this investigator‡ of the power of various flocculant solutions, as compared with water, to rise in a glass tube, shows, however, that the former rise higher and that their observed relations in this respect do not correspond with their flocculant activities as ascertained by Schlösing and Hilgard.

The observations of King§ do not, however, fully accord with Whitney's in respect to the influence of lime upon the capillary movement of water; for he found that the rate at which water passed upward through columns of coarse sand and away by evaporation, was decreased rather than increased by the addition of lime water, thus indicating for the latter a lower capillary power.

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*Storer. *Ib.*, p. 145.
†*Cf.* Whitney, Bull. 4, U. S. Weather Bureau, p. 21.
‡*Ib.* pp. 15 and 16.
§The Soil, pp. 177-8.

### DURATION OF EFFECT.

Whatever be the explanation, the fact remains that the "lightening" effect upon such soils resulting from liming is very marked and often lasts for years.

### INFLUENCE UPON WATER MOVEMENT.

Pearsen* has noted the interesting fact that a clay soil which allowed a layer of water only five centimeters (two inches) deep to penetrate through it in no less time than twenty-nine days and nineteen hours, when mixed with 2.5 per cent. of lime, permitted the completion of the percolation in only seven hours.

In case of such a soil lying upon a steep slope, it is readily seen that one result of liming would be the readier percolation of the water through the body of the soil with a correspondingly lessened tendency to form rivulets upon the surface, which might wash it into gullies; nor would the percolation be accompanied by the removal of the finer particles of the soil.

### MODIFYING EFFECT OF THE LIME ALREADY IN THE SOILS.

Hollemann,† working upon stiff clays at Groningen, Holland, found their porosity improved by addition of lime in the form of carbonate, whenever the quantity of lime in the soil was less than 0.15 per cent.; but that no benefit was perceptible from its application when the soil contained as much as 0.5 per cent.

King‡ observes that there appear to be some exceptions to the general rule that the presence of calcium carbonate ensures the friability of fine clays, from the fact that there are many clays, very impervious to water, plastic and adhesive, which are unfitted for use in making brick or pottery, because of the lime they contain, the amount sometimes reaching 5 per cent. As a possible explanation, this writer suggests that it may be that the lime, once in the impervious clay, could not be acted upon by the carbonic acid sufficiently to form enough acid carbonate of lime to effect the flocculation.

### INJURY FROM LIMING CLAYS.

It is, however, distinctly recognized that the too frequent and copious applications of lime even to clay soils may eventually render them hard and compact, instead of friable and open. In this case, the cementing action of the calcium carbonate formed in the soil appears to more closely resemble that observed in the case of ordinary mortar.

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*Chemical News, 1892, p. 53.
†Ldw. Vers.-Station, **41**, 37.
‡The Soil, pp. 30-31.

A similar injury results from the application of large dressings of caustic lime upon a clay when it is in a wet condition. On very wet clays, draining should precede liming.

### MECHANICAL EFFECTS UPON LIGHT SOILS.

Observations upon the influence of lime upon the texture of light soils are more divergent in their conclusions. Many correspondents in this State affirm that the application to light soils makes the latter more retentive of moisture and that this is more true of shales and gravels containing considerable proportions of fine particles than it is of sharp sands or even of alluvial sand deposits. It is noted in particular that the liming of the blue slate uplands of Fulton and Bedford counties has so increased the retentiveness of the soil for moisture, that clover can be made to live through the summer, where, without liming, it dies from drought. These statements accord with experience elsewhere.

### EXPERIMENTS UPON THE INFLUENCE OF LIME AND MAGNESIA UPON THE WATER CAPACITY AND HYGROSCOPIC COEFFICIENT OF SOILS.

Upon the several soils under treatment in the experiments conducted in my laboratory, no observations were made to determine the effect of the several treatments upon the rate at which water would percolate through them. But determinations were made by Mr. C. P. Beistle, Assistant Chemist, of the water-holding capacities and the hygroscopic coefficients, or power to absorb water vapor, of the several lots of soil. For the former determinations, the dry soils were weighed into tared glass funnels, upon uniform filter paper, and water was then added until the soils were saturated; when drops ceased to come through the funnel, the tops being covered to prevent evaporation, the funnels were weighed with their contents, and the quantity of water retained was thus ascertained.

For the latter determination, one portion of soil was taken for the estimation of water held under laboratory conditions; another portion was exposed for twenty-four hours upon an open watch-glass in a box so constructed that the air it contained should be saturated with water vapor.

The gain in weight due to the absorption of water, plus the weight of vapor already present, gives, when figured in percentage upon the basis of the dry soil, the hygroscopic coefficient.

TABLE VII—Moisture Relations of Soils.

| Soil. | Water-holding Capacity (Per cent.) | | | Hygroscopic Coefficient. (Per cent.) | | |
|---|---|---|---|---|---|---|
| | Blank. | Lime. | Magnesia. | Blank. | Lime. | Magnesia. |
| I. Ironstone, | 46.15 | 47.53 | 47.40 | 3.60 | 3.59 | 3.27 |
| II. Black slate, | 53.65 | 54.15 | 54.40 | 2.95 | 2.87 | 2.86 |
| III. Red shale clay, | 47.15 | 43.53 | 43.85 | 1.67 | 1.78 | 1.57 |
| IV. Limestone clay, | 49.03 | 51.53 | 47.15 | 1.80 | 1.84 | 1.53 |
| V. Glacial clay, | 48.78 | 47.53 | 50.40 | 1.69 | 1.85 | 1.69 |
| VI. Muck, | 77.89 | 82.53 | 79.40 | 4.68 | 4.94 | 5.23 |
| VII. Limestone clay, | 52.89 | 49.01 | 51.52 | 1.58 | 1.59 | 1.98 |
| VIII. Loam, | 49.98 | 47.11 | 50.39 | 2.37 | 2.44 | 2.39 |
| IX. Red shale, | 54.98 | 54.36 | 54.98 | 2.28 | 2.23 | 2.14 |

As regards the water-holding capacity, it is to be remarked that the range of difference exhibited by the several untreated soils is not large, viz: from about 46 to 78 per cent.; the muck soil in particular shows a strikingly low capacity; it is entirely possible that in the case of this soil, the porosity was impaired by the sifting through so fine a mesh. The influence of the liming is not clearly marked so far as its influence upon the empty space and arrangement of particles is indicated by the water-holding capacity of the soils; in four instances of varied character, the capacity seems to increase: in five, to diminish slightly; the magnesia exerted as marked an influence, but in samples IV, V and VII, its action was opposite to that of the lime. It is probable that, to exhibit the characteristic change, the conditions of after treatment of the soil have not been favorable. It is hoped to repeat the work under other conditions, but time has not permitted the repetition prior to the preparation of this report. Bearing upon the importance of these conditions, the old observations of Zengar* and Wilhelm† that the pulverization of soils consisting of porous particles such as lime-sinter or peat, to some extent destroys their porosity and power to retain liquid water, may be recalled.

As regards the hygroscopic coefficient, or power to take up moisture vapor, likewise, there is no clear indication that the lime or magnesia exercises any clearly marked influence, and the experiment must be repeated upon portions of soil not treated as those must be which are to be subjected to chemical analysis. Hilgard‡ affirms, however, that this power to take up moisture vapor depends essentially upon one or more of four substances, *humus*, *ferric hydrate*, *clay* and *lime*, named in the order of their efficiency. "It varies," he says, "from 1.5 to 23 per cent. at 150 degrees Centigrade in a saturated atmosphere. A pure clay rarely exceeds 12 per cent.; ferruginous clays show 15 to 21 per cent.; some calcareous clays rise nearly as high; while peaty soils rise to 23 per cent. or more.

*Wilda's Centralblatt, 1858, **1**, 430.
†*Ib.* 1866, **1**, 118.
‡X Census, **5**, 71.

### LIME PAN.

One other point of some importance relating to the texture of soils is the tendency noted on stiff soils, the plow depth of which is not varied with some frequency, to form a hard pan or compact layer between the surface and sub-soil. Once formed, it is the tendency of the alkaline silicates, humates and lime carbonate brought to it by the leaching of the surface soil to form a strong layer that prevents the proper upward movement of sub-soil moisture in dry seasons and the free downward movement of the plant roots. Heavy liming, after such a pan is formed, often greatly increases it, forming what is known as lime-pan. This formation is readily prevented, however, by proper liming; but it would be well to be sure that the land is free from hard-pan before heavily liming it.

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## The Chemical Effects of Liming.

When the action of lime upon various individual minerals and upon distinct organic materials such as starch, albuminoids, etc., is studied, it is found to be quite variable with the nature of the substance acted upon. That the introduction of so powerful a chemical reagent into those highly differing and always complex mixtures of mineral and vegetable matters that we term "soils," should result in a great variety of effects is not, therefore, surprising. In the discussion following, attention will be chiefly confined to a few of the practically more important points, considering first those relative to the mineral matters and, second, those affecting the organic matter (humus) and nitrogenous substances.

### MOST SOIL CONSTITUENTS UNAVAILABLE TO PLANTS.

Before speaking in detail upon these subjects, it may be remarked that while plants are able to take up directly from freshly pulverized rock materials small quantities of the several plant foods the latter contain, the mineral substances must usually undergo quite radical changes by the action of weather and decaying vegetation before they are really in condition to make a fertile soil. Before they are thus changed, many of them resist the action of quite strong acids; among such minerals are included the widely distributed and important minerals, quartz, feldspar, mica, hornblende, augite, tale, steatite, kaolinite, chrysolite and chlorite.* It is not, therefore, a matter of

*Johnson, How Crops Grow, 329.

surprise that in even rich soils, only 50 to 150 parts in 100,000 are capable of being dissolved in water.

It must, of course, be admitted that the plant is not wholly confined in its feeding upon mineral matters to the water-soluble substances; for the acid surfaces of the rootlets and root-hairs are able to take up some mineral matters through their cell walls in much the same manner as the acid strawberry, in the course of preparation for table use, takes up and is sweetened by the coarse, dry, granulated sugar spread upon it.

We have, however, not discovered a chemical reagent which will closely represent in its action upon the soil, the action of the plant during a single growing season. While it is thought that the mineral matter soluble in hydrochloric acid may fairly represent the ultimate fertility or cropping strength of soils, various organic acids or solutions of their salt have been proposed as reagents to show the more immediately available plant food, such as the plant could probably utilize at once if opportunity occur; these do not all closely correspond in their action with that of various plants, and it is highly improbable that a single solvent could do so for all plants and soils; but they are of considerable value as indicators of the readiness of the various more important soil ingredients for use by the plants, and to afford rough suggestions as to the need for the application of the several manurial constituents.

### LIME UNLOCKS PLANT FOOD ALREADY IN SOIL.

So it has come to be said that only a small proportion of the food substances in most soils are immediately ready for plant use; that the less soluble foods are, as it were, locked up in a safe, and that lime is one of the keys by which the safe may be opened and some of its contents made accessible to the crop. If, however, the soil be devoid of compounds such as lime can convert into available plant food, the addition of lime can cause no increase in the material fertility of the soil except as lime itself may be needed by the plants.

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## Liberation of Potash.

### POTASH IN SOIL CHIEFLY INSOLUBLE.

Though the commercial potash compounds are nearly all soluble—with so few exceptions that the chemical methods for the separation of potash from other bases are very limited in number—most of the

potash present in the soil exists there in insoluble or difficulty soluble combinations. Drainage waters contain, as a rule, much less of it than of soda, lime or magnesia. Thus Way,* upon examining the drainage waters from seven fertile soils near Surrey, Eng., found in four cases, only traces of potash, and in the others, only 0.03, 0.07 and 0.31 parts in 100,000 parts of the water. Krocker† found, in the summer drainage, from poor soils, only 0.2 to 0.6 parts in 100,000 of the water, but Zöller,‡ in five waters of percolation collected during the summer from a number of soils near Munich, found 0.20 to 0.65 parts in 100,000. Dehérain,§ studying the drainage of the experiment farm at Grignon, France, found that on highly manured land the drains in one year removed 0.2 per cent. of the entire acid-soluble potash present, while from unmanured lands, only 0.05 per cent. of the entire amount of potash was removed. Where a proportion of water larger than that found in the soil is used in extraction, or where a soil is exposed to the action of renewed portions of water, larger amounts of potash are found to be dissolved.

### POTASH IN FERTILIZERS FIXED BY SOILS.

Furthermore, if a given amount of some potash salt be added to a sample of soil and, after the mixture has stood for a short time, the earth be washed with water and the washings compared with those obtained by the extraction of an equal quantity of the unmixed earth with an equal quantity of water, it is found that the potash extracted from the former soil is far less than the sum of that in the potash salt and that extracted from the unmixed earth; in other words, it is distinctly evident that much of the potash in soluble fertilizer salts is quite promptly changed in the soil into insoluble or difficultly soluble compounds. The time required for the completion of this fixing action—so far as it goes, for all the fertilizer potash is never fixed,—Peters‖ found, in case of one soil, to be forty-eight hours.

### SOLVENT ACTION OF LIME.

The solvent action of water is, however, very greatly increased when lime, whether as a hydrate, as acid carbonate, or in chlorid, sulfate, nitrate or similar soluble salt, is dissolved in it. The work of Johnson, Way, Liebig, Brustlein, Peters, Knop, Heiden, Armsby and others, has shown most clearly that the lime in such solutions displaces some of the potash of the soil, the displaced alkali being extracted while an equivalent quantity of lime is fixed in the soil. This probably explains the fact noted by Hilgard** that sometimes a

*Jour. Roy. Ag. Soc., **17**, 133..
†Jour. prak. Chem., **60**, 466; *Cf.* Johnson, How Crops Feed, 314.
‡Johnson, *Ib.* 315.
§Traité de Chimie agricole, 426-7.
‖Ldw. Vers.-Stat., **2**, 140.
**X Census, **5**, 78.

soil very rich in lime and phosphoric acid, shows a good productiveness despite a very low potash content; and, conversely, sometimes a high potash content seems capable of offsetting a low lime percentage—it being true that potash salts when added in solution to a soil, liberate some lime with the fixation of an equivalent amount of potash.

### NATURE OF COMPOUNDS ATTACKED BY LIME.

When the nature of the compounds in the soil that are acted upon by the lime with a resulting liberation of potash, is studied, it is found that, for the most part, they belong to two great classes: hydrous soluble silicates, probably belong to the zeolitic class, and double salts of the acids of humus—humates and ulmates. M. Johnstone,* in studying the compounds that result from the weathering of feldspars—anhydrous double silicates of alumina with potash, soda or lime—states that when carbonic acid is present in large quantity, the potash is set free as carbonate; but that when such excess of carbonic acid is lacking, the potash remains in combination with silica; if, then, lime be added, it displaces the potash, forming the lime silicate and setting the potash free, as it has been found to do in acting upon the pure zeolitic minerals.

Mulder† has found that humic and ulmic acids form double salts of the alkalies with lime, magnesia, iron, manganese and alumina. It is doubtless due, at least in large measure, to a displacement of potash by lime in a manner analogous to that observed in the case of the double silicates, that liming soils poor in such silicates but containing humus, results in the increase of available potash.

### SOLVENT ACTION OF MAGNESIA.

According to Kellner,‡ magnesia and magnesium salts act in a manner similar to lime. Peters,§ testing the solvent power of the saline solutions of a number of bases, including lime and magnesia, upon equal portions of a well-washed soil, found that the magnesia solution took out 0.1224 grammes of potash, while lime removed 0.1252 grammes, or with a slight correction for the lack of precise chemical equivalence in the solvent used, the magnesia salts had 90 per cent. of the activity of the corresponding lime salt.

### AMOUNT OF POTASH IN SOILS EXPERIMENTED UPON.

Turning now to the soils subjected to test in our experiments: The proportion of potash in the solutions prepared for the determinations of lime and magnesia, the results of which have been stated in an earlier paragraph, was determined by Mr. C. W. Norris in accord-

*Naturw. Rundschau, 1891, 323; Exp. Sta. Record, 3, 581.
†Chemie der Acker Krume, quoted by Johnson, How Crops Feed, 2301-1.
‡American Fertilizer, 6, 245.
§Johnson, How Crops Feed, 341.

ance with the official method. To gain a better notion of the availability of the potash in the several soils, Mr. Norris also determined the proportion of potash extracted by water under the following conditions:

One hundred grammes were soaked with 1,000 c. c. of distilled water at summer temperature (23 degrees C., or 73 degrees Fahr.), for seven days, the flask being thoroughly shaken several times daily. The liquid was then drawn off and the fine silt in suspension allowed to settle. In a given fraction of the clear liquid the potash was determined.

In a study of soil solvents made, several years since, by Dr. Bernard Dyer, Chemist to the Royal Agricultural Society, England, upon certain soils of the Rothamsted Experiment Station, England, and checked by the analytical crop and fertilizer records, remarkably indicative results were obtained by using a 1 per cent. citric acid solution as the solvent.

The several soils tested were, therefore, examined before treatment with lime, by the use of this solvent. Mr. C. P. Beistle, Assistant Chemist, made these determinations in the following manner: 200 grammes of the air-dried soil was exposed for seven days at summer temperature (73 degrees Fahr.), to the action of two litres of a 1 per cent. solution of citric acid; the mixture was shaken several times daily. At the end of the seven-day period the liquid was decanted off and carefully filtered. In a given fraction of the filtrate, the potash was determined in the manner recommended by Dyer, save that the heavy metals, phosphoric acid, etc., were first precipitated and filtered off.

The results of these three sets of determinations are given in the following table, the figures being the average of two or three closely concordant determinations:

TABLE VIII.—Potash in the Original Soils. (Per Cent.)

| Soil Sample. | Moisture. | In per cent. of the Entire Soil. | | | In per cent. of the Potash Soluble in HCl. | |
|---|---|---|---|---|---|---|
| | | Total. | Citric acid soluble. | Water soluble. | Citric acid soluble. | Water soluble. |
| I. Ironstone, | 2.37 | .325 | .0133 | .0080 | 4.1 | 2.5 |
| II. Black slate, | 2.00 | .835 | .0220 | .0071 | 2.5 | 0.8 |
| III. Red shale clay, | 1.29 | .460 | .0107 | .0050 | 2.3 | 1.1 |
| IV. Limestone clay, | 1.64 | .805 | .0136 | .0063 | 1.7 | 0.8 |
| V. Glacial loan, | 1.96 | .270 | .0117 | .0071 | 4.3 | 2.6 |
| VI. Muck, | 4.85 | .220 | .0450 | .0290 | 20.5 | 13.2 |
| VII. Limestone clay, | 1.36 | .340 | .0190 | .0120 | 5.6 | 3.5 |
| VIII. Loam, | 1.49 | .330 | .0150 | .0130 | 4.5 | 3.9 |
| IX. Red shale clay, | 1.73 | .415 | .0150 | .0130 | 3.6 | 3.1 |

The differences in the quantity of water are very small, except in the case of the muck as compared with the other soils; even in the latter case, the correction would be an increase in the percentage of potash in the muck amounting to only one-thirtieth of the portion extracted by the several solvents. Comparisons may, therefore, be made on the basis of the figures as they are stated above. So far as the total amount of potash extracted by strong acid is concerned. No. II, black slate, and No. IV, limestone clay, contain by far the larger quantities, and No. VI, the muck, contains least; while the other soils do not differ very greatly from one another.

The editor of the Handbook of Experiment Station Work (p. 313), notes that this element is capable of great variation without materially affecting the productiveness of the soil. In heavy clay uplands it ranges from 0.8 to 0.5 per cent.; in lighter loams from 0.45 to 0.3; in sandy loams below 0.30., and in sandy loams of great depth may fall below 0.10 with good productiveness and durability.

Hilgard* says "No virgin soil having 0.50 per cent. of potash will wear out first on that side of its store of plant food; and much less will suffice in the presence of much lime and humus."

### WATER-SOLUBLE POTASH.

When we turn to the consideration of the condition in which the potash exists in the soil, several striking facts are apparent. The muck, notwithstanding its low proportion of total potash, contains over twice as much water-soluble potash as an equal weight of any other of the soils, and about six times as much as is present in No. III, red shale clay; looking simply at the percentage of the total potash that is present in water-soluble condition, it is seen to be over sixteen times as great in the muck as in Nos. II and IV. On the contrary, the soils containing the highest percentages of potash soluble in strong acid, Nos. II and IV, are among those containing least of this ingredient in water-soluble condition. The source of the soil, as regards the kind of rock from which it is formed, is not necessarily an indication of its present composition and fertility; thus, compare the limestone clays, IV and VIII, and the red shale clays, III and IX, and quite important differences in the amount and condition of the potash are visible.

### TOTAL AVAILABLE POTASH.

Turning to a consideration of the potash dissolved by the citric acid method, none of the soils show less than 0.01 per cent., and so should scarcely be regarded as extremely impoverished. Dyer† suggests that there is no immediate need of potash-manuring, if the citric soluble potash in the soil form 0.005 per cent. of the dry soil. In this case, too, the muck shows both the largest percentage and the largest amount, while Nos. I, III, IV and V contain the least amounts.

*Rep. Cal. Exp. Station, 1889, 166.
†Jour. Chem. Soc., 1894.

POTASH IN SOILS AFTER TREATMENT.

The treated soils were also examined with reference to the amount and condition of the potash contained. The total potash soluble in strong acid was determined by Mr. C. W. Norris, that soluble in citric acid solution by Mr. C. P. Beistle. In the latter determination a sufficient quantiy of citric acid was used, beyond that required to make a 1 per cent. solution, to neutralize the lime added and magnesia in the samples that represented the results of treatments B and C, so that the neutralizing effect of these alkaline earths might not too greatly interfere with the solvent action of the liquid.

The results are shown in the following table. Owing to the fact that the quantity of the lime and magnesia added in treatments B and C would not, even if fully carbonated by action of the air of the soil, come to equal 1 per cent. of the weight of the entire soil, it has not been deemed needful to correct for the error introduced by this addition, to permit a direct comparison between the results of treatment A and those of B and C. For safety, the moisture of the samples was determined in each case; the difference between the several treated samples and the original soils were, however, so slight that these results may be omitted.

TABLE IX—Potash in the Treated Soils. (Per Cent.)

| Soil. | Treatment A. (Fallow). | | | Treatment B. (Lime.) | | | Treatment C. (Magnesia.) | | |
|---|---|---|---|---|---|---|---|---|---|
| | Soluble in strong acid. | Soluble in citric acid. | Proportion of potash soluble in citric acid. | Soluble in strong acid. | Soluble in citric acid. | Proportion of potash soluble in citric acid. | Soluble in strong acid. | Soluble in citric acid. | Proportion of potash soluble in citric acid. |
| I. Ironstone, | .262 | .0133 | 5.1 | .242 | .0155 | 6.4 | .222 | .0176 | 8.0 |
| II. Black slate, | .760 | .0220 | 3.0 | .753 | .0241 | 3.2 | .720 | .0243 | 3.4 |
| III. Red shale clay, | .298 | .0116 | 3.9 | .265 | .0140 | 5.3 | .345 | .0150 | 4.4 |
| IV. Limestone clay, | .543 | .0172 | 3.2 | .572 | .0200 | 3.5 | .557 | .0178 | 3.2 |
| V. Glacial loam, | .195 | .0132 | 6.8 | .185 | .0150 | 8.1 | .225 | .0162 | 7.2 |
| VI. Muck, | .217 | .0320 | 14.7 | .210 | .0340 | 16.2 | .217 | .0334 | 15.4 |
| VII. Limestone clay, | .315 | .0116 | 3.7 | .310 | .0162 | 5.2 | .302 | .0208 | 6.9 |
| VIII. Loam, | .395 | .0128 | 3.2 | .365 | .0144 | 3.9 | .370 | .0168 | 4.5 |
| IX. Red shale clay, | .438 | .0134 | 3.1 | .450 | .0208 | 4.6 | .448 | .0176 | 3.9 |

Examining these figures critically and comparing them with the percentages obtained in the case of the original untreated soils, some very striking discrepancies are seen, especially in the cases of Nos. II, III and IV. Some discrepancy is also apparent in the figures for potash soluble in strong acid obtained from each soil after the different treatments. The latter fact and the further fact that the results are the averages of several separate analyses in each case, lead to the conclusion that the discrepancies are chiefly due to the difficulty in getting perfectly uniform samples of soil, even when great care is exercised.

So far as the potash soluble in strong acids is concerned, there seems to be no evidence in the figures above presented to the effect that the lime or magnesia especially influences the amount of potash that is capable of extraction with such vigorous solvent. There are variations, it is true, in the percentages shown by samples from different treatments of the same soil, but comparing the lime and fallow treatments in their action upon red shale clays, Nos. III and IX, the figures would show exactly opposite effects. It would, however, not be safe on the basis of these analytical results to affirm positively that lime and magnesia have no tendency to attack minerals little soluble in strong acids, and, in greater or less degree, to aid the increase of their availability through the process of weathering.

### EFFECT OF FALLOWING.

It may, however, be true that the availability of the potash in the different portions of the same soil is more uniform than is the amount of potash itself. On the basis of this assumption, compare the citric-acid-soluble potash in the original and fallow soils. Despite the opposite tendency of the total potash soluble in strong acid, in soils I, II, III, IV and V, inclusive, after fallow treatment, the proportion of the entire soil present in citric-acid-soluble potash is as great or greater than in the original soils; in the muck soil, the quantity of such potash is materially less in the fallowed soil; in soils VII, VIII and IX it shows a slight decrease; expressed in terms of the entire acid-soluble potash, that soluble in citric acid in the fallow soils is greater in soils I, II, III, IV and V; is somewhat less in soils VII and VIII and markedly less in the muck soil.

### EFFECT OF LIMING.

Turning attention now to the effect of lime, recalling that the soils in Treatment A were exposed to precisely the same conditions as those subjected to the other treatments, we may fairly compare the figures from Treatments A and B to ascertain the effect of the liming. Without exception, the "available" potash, or that soluble

in citric acid, was increased. If the proportion of the entire soil represented by the "available" potash is considered, it is found that from 16 to 74 pounds, or an average of 30 pounds per million pounds of soil is present in the limed soil. This may appear to be very little, but as little as twenty pounds of nitrate of soda applied to an acre has been found to influence the plant growth and such application is equivalent to no more than 1 pound of nitrogen to 1,000,000 pounds of soil. The larger effects were observed on the limestone clay, No. VII, and on the red shale, No. IX, which, in their original state, contained nearly 0.3 per cent. of lime. Such increase represents, of course, a larger proportion in case of soils poor in potash.

### EFFECT OF MAGNESIA.

Looking finally to the effect of the magnesia as shown by a similar comparison between the figures from Treatments A and C, the "available" potash is increased from 6 to 92 pounds, or an average of 36 pounds per million of soil. In general, the unlocking or liberating of the potash seems to have been about as well accomplished by the magnesia as by the lime. The ironstone soil, No. I, and limestone clay, No. VII, exhibited the most marked effects from the magnesia treatment. Nothing in the composition of the original soil, as revealed by the analyses made, explains its greater effect upon these soils.

Taking the averages for the nine soils, the proportions of the total potash that was soluble in citric acid were: In the original soils, 5.5 per cent.; in the fallow, 5.2 per cent.; in the limed, 6.3 per cent., and those receiving magnesia, 6.3 per cent.

These results, therefore, agree with those of Kellner, viz: That both lime and magnesia increase the available potash in most soils, and that the magnesia is almost equal to its equivalent proportion of lime in producing this effect. It is further interesting to note that this increased availability resulted from the action of magnesia upon the muck as well as upon the soils less richly supplied with humus.

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## The Effect upon Soil Phosphoric Acid.

### SOLUBILITIES OF SOIL PHOSPHATES.

The phosphoric acid in most rocks is present in the form of tricalcic phosphate, a lime compound that is somewhat soluble in pure water, and much more soluble in water saturated with carbonic acid gas.

Bretschneider* found that in twenty-four hours at ordinary temperature one part of finely precipitated tricalcic phosphate required 87,832 parts of water to dissolve it, but only 13,181 parts of carbonic acid water. In the soil, however, a very large proportion of the phosphoric acid is present in the form of phosphate of iron (usually ferric phosphate, for the most part) or alumina. The iron phosphate is much less soluble, the same investigator having found that one part of freshly precipitated ferric phosphate requires for its solution 160,625 parts of water, or 146,570 parts of carbonic acid solution. In the latter case it is seen that the solvent action of the soil water, usually containing considerable carbonic acid, is much less, as compared with pure water, than it is in case of the lime phosphate. Fleischer† has found that water dissolves from freshly precipitated phosphate of alumina even less phosphoric acid than it takes up from the corresponding ferric compound.

Johnson‡ remarks that drainage waters commonly contain phosphoric acid but in quantities too small for accurate estimation.

### AVAILABILITY IN CALCAREOUS SOILS.

If the soil is rich in lime or magnesia it is thought probable that a fair share of the phosphoric acid will be combined with it and be quite readily dissolved by the plant roots and soil moisture; if, on the contrary, lime and magnesia are deficient, the phosphoric acid is doubtless present in its much less soluble compounds with iron or alumina.

Hilgard,§ in his study of the cotton soils of the Southern States, dwells upon this point. He notes that less than 0.05 per cent. of phosphoric acid soluble in strong acids is a notable deficiency unless accompanied by much lime; in sandy loams, 0.1 per cent., with a fair supply of lime, secures a fair productiveness for eight to fifteen years, but with a deficiency of lime, 0.2 per cent. of phosphoric is required to produce the same result. Three Louisiana soils are cited as illustrative of this fact:

(a) Pine woods sub-soil (Vernon parish) an upland soil producing only 500 lbs. of seed cotton per acre for a few years.

(b) Oak and hickory red sub-soil, upland (Sabine parish), producing 800 to 1,000 lbs. when fresh, then declining.

(c) Anacoco prairie soil (Vernon parish) has yielded 1,200 to 1,500 lbs. for fifteen years and is still doing fairly well.

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*Quoted by Storer, *Op. cit.*, (4th ed.), I, 265-6.

†*Ib.* 264.

‡How Crops Feed, 310-315.

§X Census, 5, 78-80.

| | (a.) Per cent. | (b.) Per cent. | (c.) Per cent. |
|---|---|---|---|
| Potash, | 0.247 | 0.202 | 0.332 |
| Lime, | 0.097 | 0.268 | 1.398 |
| Magnesia, | 0.339 | 0.290 | 0.735 |
| Phosphoric acid, | 0.072 | 0.038 | 0.047 |

The observations of Gerlach,* made upon artificially treated soils, show that the phosphates of both lime and magnesia are slowly soluble in water and completely so in carbonated water; but the phosphates of iron and alumina are practically insoluble in these solvents and only incompletely so in dilute organic acids.

### LIME ATTACKS FERRIC PHOSPHATES.

There are quite a large number of observations showing that the application of lime to soils deficient in that constituent tends to increase the availability of the phosphoric acid present. Thus, Dehérain,† on mixing calcium carbonate with ferric phosphate and treating the mixture with carbonic acid water, found much tricalcic phosphate in the solution; if, however, lime phosphate was mixed with a large proportion of ferric carbonate, ferric phosphate was formed.

On the basis of this latter observation, this investigator‡ suggests that unless such considerable quantities of lime are used as will predominate over the free sesqui-oxids of iron and aluminum in the arable layer of the soil, the increased solubility of the soil phosphates will not be accomplished.

Prof. Millot§ observed that the application of soluble phosphates to a soil in the department of Loire-et-Cher which was rich in iron oxid, gave a benefit, but one very fleeting, no residual effect being observed the second year; the subsequent addition of marl brought an increase in yield such as that land never yields except with a good dressing of phosphate, indicating the restoration of the phosphoric acid to an available condition. This is a fair type of many such observations.

### PHOSPHORIC ACID IN SOILS EXPERIMENTED UPON.

Turning now to the soils taken for experiment: The amounts of phosphoric acid contained in the several solutions made by extraction of these soils, were determined, in the strong acid and water solutions, by Mr. Norris, and in the citric acid solution by Mr. Beistle. In the latter solution, the results are somewhat unsatisfactory because

*Ldw. Vers. Stat., **46**, 201.
†Comptes rendus, **46**, 212.
‡Traité de chimie Agricole, 525.
§*Loc. cit.*

of the difficulty of prefectly removing the finest particles of soil from the liquid, so that the phosphoric acid obtained represents that in the small particles of soil as well as in the real solution; in determining the potash, the figures for which have already been presented, the chemical methods that were employed threw out the silt, which was not practicable in determining the phosphoric acid:

TABLE X—Phosphoric Acid in the Original Soils. (Per Cent.)

| Soil Sample. | Percentage in Entire Soil. | | | Proportion in Available Form. | |
|---|---|---|---|---|---|
| | Soluble in strong acid. | Soluble in citric acid. | Soluble in water. | Citric acid soluble. | Water soluble. |
| I. Ironstone, | .060 | .0057 | .0032 | 9.5 | 5.3 |
| II. Black slate, | .204 | .0111 | None. | 5.4 | 0.0 |
| III. Red shale clay, | .080 | .0088 | .0016 | 11.0 | 2.0 |
| IV. Limestone clay, | .140 | .0082 | .0033 | 5.9 | 2.4 |
| V. Glacial loam, | .092 | .0130 | .0040 | 14.1 | 4.3 |
| VI. Muck, | .206 | .0628 | .0015 | 30.5 | 0.7 |
| VII. Limestone clay, | .124 | .0139 | .0027 | 11.2 | 2.2 |
| VIII. Loam, | .127 | .0146 | .0005 | 11.5 | 0.4 |
| IX. Red shale clay, | .151 | .0306 | .0045 | 20.3 | 3.0 |

As for the phosphoric acid soluble in strong acid: Hilgard's average from 466 soils from the humid regions of this country, especially the Southern States, is 0.113 per cent.; from 313 soils from the arid regions, 0.117 per cent.; in general, clay soils were considerably richer than sands. In view of these averages, most of the above soils are fairly well supplied with phosphoric acid, Nos. I, II and V containing least, but even these are not very deficient.

Dehérain* observes that in estimating the sufficiency of the phosphoric acid in a soil, not only its richness as exhibited by analysis, but its depth must be considered in determining the need for phosphatic fertilizers. Thus, he says, M. Nantier, director of the Agricultural Station of Somme, found, near Amiens, a soil containing 0.25 per cent. of phosphoric acid, of which much was available, as shown by the solubility of one-tenth in acetic acid; yet a phosphate dressing increased the yield per acre (French) of beets from 28,500 to 45,000 kilogrammes; for the soil was only from six to eight inches deep, and had scarcely more available phosphoric acid in that depth of soil than one crop would require. He suggests that unless a soil contains more than 0.1 per cent. of phosphoric acid, and more than 0.02 to 0.03

*Traité de Chim. agricole, 730-1.

per cent. of available phosphoric acid, with such depth of surface soil that the amount of available acid therein shall not be less than about 900 lbs. per acre, phosphate manuring is needed.

### AVAILABILITY OF THE PHOSPHORIC ACID.

The condition in which the phosphoric acid exists in the several soils is evidently very different; thus, samples II, VI and VIII, despite their comparatively high proportion of phosphoric acid, contain very little that is soluble in water, even less than III, which contains so much less of phosphoric acid as a whole. In No. I, which contains the least of all, there is the largest proportion of the phosphoric acid soluble in water.

Considering the total available phosphoric acid as indicated by the proportion in the entire soil soluble in citric acid, the muck is richest and the red shale clay, IX, next, while the ironstone, I, contains least. Only I, III and IV contain less than 0.01 per cent., the figure fixed by Dyer as indicating need of immediate phosphate application.

### PHOSPHORIC ACID IN SOILS AFTER TREATMENT.

The effects of liming and application of magnesia upon the availability of the phosphoric acid are shown in the following table:

TABLE XI—Phosphoric Acid in Treated Soils. (Per Cent.)

| Soil. | Treatment A. (Fallow). | | | Treatment B. (Lime.) | | | Treatment C. (Magnesia.) | | |
|---|---|---|---|---|---|---|---|---|---|
| | Soluble in strong acid. | Soluble in citric acid. | Proportion of phosphoric acid available. | Soluble in strong acid. | Soluble in citric acid. | Proportion of phosphoric acid available. | Soluble in strong acid. | Soluble in citric acid. | Proportion of phosphoric acid available. |
| I. Ironstone, | .095 | .0082 | 8.6 | .098 | .0107 | 10.9 | .099 | .0096 | 9.7 |
| II. Black slate, | .227 | .0100 | 4.4 | .233 | .0090 | 3.9 | .205 | .0109 | 5.3 |
| III. Red shale clay, | .089 | .0080 | 9.0 | .084 | .0107 | 12.7 | .080 | .0110 | 13.8 |
| IV. Limestone clay, | .147 | .0064 | 4.4 | .139 | .0152 | 10.9 | .164 | .0126 | 7.7 |
| V. Glacial loam, | .091 | .0100 | 11.0 | .088 | .0132 | 15.0 | .090 | .0164 | 18.2 |
| VI. Muck, | .206 | .0496 | 24.1 | .231 | .0574 | 24.8 | .241 | .0610 | 25.3 |
| VII. Limestone clay, | .124 | .0090 | 7.3 | .142 | .0138 | 9.7 | .163 | .0162 | 9.9 |
| VIII. Loam, | .152 | .0084 | 5.5 | .161 | .0124 | 7.7 | .135 | .0160 | 11.9 |
| IX. Red shale clay, | .135 | .0178 | 13.2 | .152 | .0258 | 16.9 | .145 | .0320 | 22.1 |

While differences in the total phosphoric in the original soil and the corresponding treated soils are observed, just as was the case with potash, the general relations are the same in both the original and treated soils.

### EFFECT OF FALLOWING.

Comparing the original and the fallow soils, as regards the proportion of the phosphoric acid in available condition, the latter shows an invariably smaller proportion than the former; this is not always very marked, but in some cases, such as III, V, VI, VII, VIII and IX, for instance, the decrease is considerable.

### EFFECT OF LIMING.

Compared with the fallowing, the treatment with lime results in a larger availability of the phosphoric acid than where soil lies fallow, except in the case of II; it is possible that a predominance of iron and alumina in the latter soil may account for this, but as no determinations of iron and alumina were made, it is not certain that this is the correct explanation. On the muck, the liming seemed not to have caused any increase in the availability of the phosphoric acid or to have entirely prevented a decrease; the greatest increases occurred in soils IV, V and IX.

### EFFECT OF APPLYING MAGNESIA.

Considering the effect of magnesia, its general tendency was to act as powerfully, at least, as lime. Indeed, if we may form an estimate of the influence of the different treatments upon the availability of phosphoric acid, the following averages will be suggested: Of the total phosphoric acid, the critric acid took from the nine soils by Treatment A, 9.7 per cent.; by Treatment B, 12.5 per cent.; by Treatment C, 14.0 per cent. While inference from averages is not always safe, it does not seem that lime acted in these cases more effectively than magnesia; in soils V, VIII and IX the increase with magnesia was much the greater, while IV showed a considerably less effect than lime. As in the case of lime, soils II and VI alone failed to show a marked increase in the availability of the phosphoric acid.

### INFLUENCE UPON SUBSEQUENT APPLICATION OF PHOSPHATES.

There is another important consideration in the use of lime, viz: Its influence upon the immediate availability and upon the duration of effect of phosphatic fertilizers applied to a limed soil.

### REVERSION OF PHOSPHORIC ACID IN FERTILIZER.

It is a well-known fact that in the manufacture of super-phosphates, if the soluble phosphoric acid, or rather water-soluble phosphates

formed by the action of sulfuric acid upon tricalcic phosphate, the so-called "bone phosphate of lime," be brought into contact with wood ashes, lime or even fresh portions of raw phosphates, the soluble compounds will be wholly or in part reverted or reconverted into tricalcic phosphate, differing from the original only in being more finely sub-divided than is possible by a purely mechanical process. The chemically precipitated phosphate is much more soluble than that occurring in nature; thus, Warington* found that, at ordinary temperatures, there were required of water saturated with carbonic acid gas, to dissolve one part of pure precipitated tricalcic phosphate, 1,789 parts; to dissolve one part of the phosphate of lime in bone ash, 6,788 parts. Voelcker† found that 4,900 parts of water dissolve one part of pure precipitated tri-magnesia phosphate, while 12,610 parts were required for similarly prepared tricalcic phosphate.

### REVERSION IN SOIL.

Now, it is clear that very shortly after their introduction into the soil, soluble phosphates must be converted into less soluble compounds, whether of lime, magnesia, iron or alumina, unless the soil be one containing neither the earthy carbonates nor the oxids of iron and aluminum. Such soils are very rare. Farsky‡ found that in twenty-four hours, over 60 per cent. of the water-soluble phosphoric acid of acid phosphate applied to a certain soil had lost its capacity of solution in water. In such cases the principal advantage of acidulation of the phosphate must be found in its more thorough dissemination in the soil and in the finer state of subdivision obtained than can be secured by the mechanical pulverization and stirring in of raw phosphates.

### IN NON-FERRUGINOUS SANDY SOILS AND PEATS.

In non-ferruginous sands and peaty soils, the addition of lime would result in a quicker conversion to less soluble form, of any acidulated phosphate later applied. In the absence of lime, this "fixation" would not occur and while the soluble phosphate could be somewhat more promptly taken up by the plant, it is far more likely to lose by leaching and to cause injury to the crop by over-concentration. Soils that are artificially deprived of basic material by action of strong acids, exhibit a similar inability to "fix" phosphoric acid.

### IN FERRUGINOUS SOILS.

In the absence of lime or magnesia, there is a tendency to immediate union with iron oxid or alumina, with the result of an almost

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* *Cf.* Storer, I, 262.
†*Loc. cit.*
‡Rep. Pa. Agr. Exp. Station, 1887.

immediate loss of availability. It is, therefore, urged in behalf of lime and magnesia that their presence results in a far greater duration of effect from super-phosphates than could otherwise be secured; and their application to a non-calcareous soil must greatly increase the value of later applications of soluble phosphates as well as increase the availability of the phosphatic compounds already present in the soil.

Kellner, Sakano, Sato and Shinjo* found that lime added to a deep, yellow sub-soil of an irrigated field did not prevent the quick conversion of a subsequently applied dressing of water-soluble phosphate into a form not capable of solution in neutral ammonium citrate. This may have been because the quantities of lime applied (equivalent to from 0.25 to 5.0 per cent. of the soil) may not have equalled the oxids of iron and alumina present. On a "paddy" soil of the same geological origin, but rich in organic matter, the lime retarded the formation of the insoluble phosphates, especially where the proportion of lime was over 1 per cent. of the air-dry soil. Kellner believes, however, that the humus of the paddy soil is useful in accomplishing part of this retardation.

### IN CALCAREOUS SOILS.

Voelcker† notes that heavy dressings of rich super-phosphates are not nearly so valuable on the sandy soils of England as on calcareous soils.

### CHOICE OF PHOSPHATES FOR DIFFERENT SOILS.

Dehérain‡ urges that long cultivated soils are those for which soluble phosphates are best adapted. On old, non-calcareous soils he regards the basic slag phosphates, which themselves contain lime in caustic or carbonate form, as preferable; and only on old grass lands newly cultivated or on virgin soils rich in organic matter does he recommend the *trial* of non-acidulated phosphates. Bernard,§ upon the basis of numerous observations as well as upon theoretical considerations, strongly advocates the same selection.

### LIMING INCOMPATIBLE WITH USE OF NON-ACIDULATED PHOSPHATES.

Speaking of the use of lime with raw phosphates, Dehérain** observes that the latter should never be used simultaneously with lime, since the latter will prevent the solvent action of organic acids upon the phosphates. In France, where non-acidulated bone-black used to be employed as a fertilizer, it was found to yield no benefit either

*Bulletin No. 9, College of Agriculture, Tokio, Japan; Exp. Sta. Record, **2**, 764-5.
‡Quoted by Storer, II, 286.
†Traité de Chim. agricole, 769-770.
§Le Calcaire, 91-120.
**Op. cit., 760-761.

with or after a liming; if, however, the liming follows a year later, an increase in the efficiency of the phosphoric acid, by that time partially changed to the iron and aluminum compounds, was exhibited, from causes already explained. These remarks apply better to raw lime phosphates than to those of iron or alumina.

### FIXATION BY MAGNESIA.

Kellner* claims for magnesia also a strong influence in retarding the reversion of phosphates in the soil.

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## Influence of Lime upon the Weathering of Rocks.

### DOUBLE SILICATES INFLUENCE SOIL RETENTIVENESS.

In discussing the effect of lime as a liberator of potash in the soils, it was noted that among the minerals most largely attacked were the hydrous double silicates of potash and alumina. The investigators mentioned in that connection have found that, commonly, an excess of a potash salt or ammonium salt is capable, when introduced into a soil containing a hydrous double silicate of lime and alumina of displacing the lime and leaving the potash or ammonia fixed in the silicate. It is obvious that the presence of a goodly proportion of such double silicates must contribute very largely to that store of fertilitiy which, if not at once fully available, come into activity in response to good tillage and enables the soil to withstand the drain of heavy, continuous cropping; and, also, to the ability of the soil to take up and retain in fairly available form, without undue waste by leaching, such heavy dressings of potash and ammonium compounds as it may receive—a property often lacking in lighter soils.

### LIME PROMOTES WEATHERING AND FORMATION OF DOUBLE SILICATES.

Numerous investigations show both directly and indirectly that lime greatly promotes the weathering of minerals; thus, making their constituents available to the plant, and especially contributes to the formation of this valuable class of soil components, the double silicates. A little of the evidence bearing particularly upon this latter point may be of interest.

Hydraulic cements are found to contain large quantities of hydrous double silicates of lime and alumina; the setting under water is at-

*American Fertilizer, 6, 245.

tributed to the formation of crystals of these compounds as they complete their hydration. These cements can be artificially made by mixing certain clays of volcanic origin, or burned clays with moist lime. Many clays which themselves show little tendency to be acted upon by hydrochloric acid, as the hydrous double silicates readily are, are largely decomposed by it after having been exposed for a week or two to the action of milk of lime.

Storer* notes the fact that old mortars are often found to contain notable quantities of hydrous silicates, so that caustic lime must be able to attack even the strongly resistant grains of sand. In the same connection, he presents the results of experiments by Stöckhardt proving that lime attacks powdered quartz as well as gelatinous silica, forming a hydrous lime silicate, and that it also decomposes powdered feldspar—a mineral which resists the action of strong acids. Liming is said to be especially efficacious upon such clays as contain broken but undecomposed fragments of feldspar.

By this increase of weathering, therefore, not only is the amount of free potash made more abundant, but the retentiveness of the soil and its durability are at the same time enlarged.

Indeed, numerous laboratory experiments show that many soils gain, by admixture of lime or lime carbonates or other of its salts, greatly in their power to fix potash, soda, ammonia, etc.

It is, furthermore, evident that the liming of sandy soils, especially of those largely made up from minerals other than quartz, in addition to any value it gives in a direct contribution to the food supply in the soil, must also tend to secure a most important benefit in increased retentiveness for added fertility, a property in which such soils are very deficient.

### IMPORTANCE OF LIME IN CLAY-BURNING.

The expensive process of clay-burning so much used upon certain soils of England and Germany, a few decades since, was unproductive of any beneficial results, Lloyd states, unless lime was present in the clay. Storer† asserts, however, that all plastic clays are benefitted in texture if properly burned, but that those containing lime are most benefitted. Voelcker‡ found that a clay containing 31.38 per cent. of calcium carbonate and 58.62 per cent. of real clay gave the following results, in terms of the entire soil:

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*Op. cit.* II, 150.
†*Op. cit.*, II, 280-1.
‡Quoted by Storer, I, 283.

| | Total acid soluble. | Potash soluble in acid. |
|---|---|---|
| | Per cent. | Per cent. |
| Before burning, | 44 | 0.35 |
| Moderately roasted, | 49 | 0.77 |
| Properly roasted, | 54 | ..... |

Similar results were obtained on other soils by other investigators. Undoubtedly, therefore, one of the most important beneficial results from this treatment is found in the increased proportion of alkaline silicates and more highly available potash in the soil.

## Reactions upon the Soluble Salts of Potash and Soda.

Potash and soda are contained in soils not alone in the form of anhydrous and hydrous silicates, but also to a greater or less extent in the form of soluble salts. Upon this class of compounds, as well as the former, lime reacts with important results.

### LIME AND SALT COMPOSTS.

The use of salt with lime in composting peat and other vegetable matters has been largely practiced. The lime decomposes the salt, forming calcium chlorid and caustic soda; the latter of the two resulting compounds being the more readily diffusible, separates in a porous compost from the chlorid and reacts more powerfully than caustic lime in decomposing the vegetable matter. Prof. S. W. Johnson* found a compost of peat and ashes, with lime in one case, and lime and salt in another, gave crops of pop-corn of 43.22 and 46.42 grammes weight respectively, showing the superior activity of the latter agency for decomposition.

Storer† suggests that this may afford a possible explanation for certain exceptionally good results obtained from dressings of salt applied to limestone soil, the soda compound formed in this case being

*Cited by Storer, *Op. cit.*, II, 19.
†*Op. cit.*, II, 168-9.

the carbonate, however, rather than the hydrate, or caustic soda. A similar reaction would take place with potash salts.

### LIME AS A PREVENTIVE AGAINST INCRUSTATION.

Heinrich* notes than a frequent consequence of heavy applications of soluble fertilizers (kainit, nitrate of soda, etc.) to the soil is the formation of troublesome crusts upon the surface that are only temporarily remedied by cultivation, the next rain being followed by a reappearance of the crust. The simultaneous use of lime, preferably in the form of carbonate, with such fertilizers, is recommended by him as a very excellent preventative against the incrustation.

Lime and calcareous marls have also been found valuable as corrections for the white alkali soils of the arid regions of the west, when these soils contain much of the sulfate or chlorid of magnesium and similar salts.

### EXCESS OF ALKALINE HYDRATES AND CARBONATES MAY WORK INJURY.

It may easily happen, however, that the alkaline hydrates or carbonates that prove such valuable aids in decomposing humus, may occur in such excess as to cause decided injury. It is a well established fact that these materials have an influence upon the texture of clay soils opposite to that of lime, causing such a soil to puddle, become plastic and remain moist. Even on light, sandy soils, heavy dressings of wood ashes have produced such a degree of coherence between the particles as to make plowing a difficult matter. In the "black alkali" soils of California, Hilgard† has found large quantities of sodium carbonate and, in consequence of its influence, these soils are most refractory; furthermore, in the great excess in which the salt is present, it seems to work corrosively upon the vegetation that starts growth upon these soils.

It is entirely possible, therefore, that the reactions between the alkaline salts and lime, either the hydrate or carbonate, that occurs when large dressings of lime are applied to lands heavily impregnated with these salts, or when the latter are applied in large quantities to clay lands rich in calcium carbonate, may produce so large quantities of the sodium or potassium hydrates or carbonates as to work injury. Indeed, Heinrich‡ states that he has, in two instances, observed injurious results from the application of marl (used because of the calcium carbonate it contains), once upon land in whose neighborhood a deposit of salt was later discovered, and once upon soil that had received heavy applications of sewage, which is always rich in common salt.

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*Mergel u. Mergeln, 18.
†Bulletin 3, U. S. Weather Bureau.
‡*Op. cit.*, 16.

## Lime Corrects Harmful Influence of Ferrous Salts.

There are often found in such soils as are shut off from free access of air, such as stiff sub-soils and undrained swamps and moors, ferrous compounds produced probably by the reduction of ferric salts or ferric oxids and hydrates. Even after swamps and marshes have been reclaimed, it is probable that in the presence of the large amounts of organic matter such lands contain, there can not be an immediate, complete oxidation of such compounds to ferric forms. Maercker* asserts that the presence even of considerable quantities of ferrous oxid does not necessarily render moor earth uncultivable, so long as the iron remains in insoluble combinations, such as a double ferrous and calcic humate, for example.

While it is true that the humates and ulmates of iron are nearly insoluble in water, Mulder† found the ferrous compounds of apocrenic and crenic acids to be soluble. Since, therefore, the latter compounds are likely to occur in sub-soils and marshy lands, it is not improbable that a part of the marked infertility of fresh turned, yellow clay sub-soils and of recently drained marsh lands is due to these compounds as well as to the sulfates, whose action will be discussed later.

The cause of their injurious effect is not fully understood. The more commonly accepted theory attributes the ill effect to the avidity with which they take up oxygen, robbing the plant roots of their requisite supply.

If such soils be limed, the iron is thrown down in an insoluble form and may then be slowly oxidized without working so great injury to vegetation.

## Lime Corrects Soil Acidity.

### FORMATION OF SULFIDS IN SOILS.

In discussing the sources of the lime present in our limestone formations, mention was made of the fact that in the waters of certain

*Quoted by Storer, I, 480.
†Quoted by Johnson, How Crops Feed, 231.

springs and in the mud of the sea bottoms, calcium sulfate is being constantly reduced to the form of sulfid, largely through the agency of living organisms. A similar reduction of the sulfate of lime and ferrous sulfate occurs when they are in contact with large proportions of decomposing organic matter. Dehérain,* applying gypsum (sulfate of lime) to soils of varying richness, found after a month that from a soil moderately rich in organic matter, 0.55 gr. of sulfuric acid had disappeared, from a soil containing more humus, 0.100 gr., and from a marsh soil, 0.347 gr.

### SULFIDS OFTEN OXIDIZE TO INJURIOUS SULFATES.

These sulfids sometimes decompose, under the influence of carbonic acid, with the formation of the corresponding carbonates, the sulfur going off in the form of sulfuretted hydrogen. But in many marshes, bogs and moors they accumulate, the iron sulfid in particular.

These sulfids appear to be directly injurious to plants, but it is probable that a large part of the damage they work is due to the sulfuric acid and ferrous sulfates they form when oxidized. For Farsky† has shown that the direct addition of free sulfuric to soils is injurious to vegetation, and Mulder‡ found that humic acid liberates sulfuric acid from ferrous sulfate.

### OCCURRENCE IN MARSH LANDS.

In the reclamation of the sea bottoms practiced in Holland, the injurious action of sulfids and sulfates has been experienced and it doubtless occurs to some degree in all cases of reclamation of tide-water marshes, and of the bottoms of quiet pools and dams. It is noted, in the management of the old Acadian dyke-lands of Nova Scotia, which are flooded every few years and then again drained, that after such renovation the lands remain almost entirely unproductive for a year or two. It is possible that this is due in part to the sulfids, as well as to the sea salts taken up by the earth.

### OCCURRENCE BELOW COAL STRATA.

There are many limited areas in Pennsylvania lying just below and receiving the leachings from the coal outcrops and the contiguous slate strata, that are almost wholly unproductive because of the ferrous sulfate and sulfuric acid formed by the oxidation of the iron pyrites in the coal and slate and seeping into these lower soils.

### INJURIES BY MINE WATER.

There are also in our State hundreds of acres of once fertile river and creek bottom lands, through which pass streams receiving mine

*Traité de Chim. agricole, 546-7.
†Bied. Centralbl., 1886, 453.
‡Chemie der Ackerkrume, II, 37.

waters charged with free acid, ferrous sulfate and pyrites-containing culm, that have become sterile because of deposits of the culm upon their surface and the percolation of the acid waters into their pores. Even where the layer of culm is not heavy, the sulfates and acids formed from the pyrites often prove wholly destructive to all valuable vegetation, wild blackberries, dewberries and certain weeds taking the place. Coming upon light, sandy alluvium not very rich in lime or magnesia at the outset, such deposits work an injury that is permanent through many years, and sometimes utterly destructive if the land be left to the corrective action of natural agencies.

### LIME AS A CORRECTIVE.

If, however, lime, either in the caustic condition or as carbonate, be applied to such lands, the free acid is at once neutralized and the ferrous salt soon decomposed into harmless compounds, and even the pyrites more rapidly converted into non-injurious ferric oxid and calcium sulfate. Magnesium hydrate or carbonate would also promptly neutralize the free acid and decompose the ferrous salts.

Such dressings of lime might not be very effective, however, in case of lands injured by mine-water, if the acid water were constantly rising by percolation from the sub-soil, or if the surface soil were so situated as to receive frequent and large deposits of culm.

### LITMUS TEST FOR SOIL ACIDITY.

If the "burning" and partial or entire failure of good grasses, clover, and cereals upon the soil and the substitution of the characteristic vegetation above mentioned, is not an entirely conclusive proof of the nature of the injury, a direct chemical test may be made to determine whether or not the soil is acid. It must be frankly admitted that the existing tests used for this purpose are not as delicate and conclusive as is desired, owing, in large measure, to the action of the carbonic acid which is to some degree present in the air and moisture of most soils; consequently, the detection of slight acidity is a matter of uncertainty even when the test is applied by an experienced chemist.

The litmus test is one applicable to soils devoid of humus as well as to those rich in that constituent. Litmus is a vegetable dye which turns to a very pronounced blue tint in alkaline solution, and to a bright to pinkish red in acid solution. It is most conveniently applied by means of strips of paper dyed with the coloring matter. A few cents' worth of the blue litmus paper should be purchased from the druggist, and with as little handling as possible, placed in a stoppered or corked bottle and kept in the dark, because sunlight causes the tints to fade. The most satisfactory method proposed for applying this test is that of Dr. H. J. Wheeler:* "A tablespoonful

*Bulletin 46, R. I. Exp. Sta., pp. 100-101.

or more of soil is placed in a tumbler or cup and moistened with sufficient water to make the mass of about the consistency of thick paste; allow it to stand for fifteen to twenty minutes before making the test. With a knife-blade part the soil and insert one end of a strip of the paper, press the soil about the paper and after two to five minutes remove the paper without tearing it; rinse off the adhering soil with water and note whether it still retains a blue tint or has become positively red. If the soil has a reddish tint, it may be better to bring but one side of the paper into contact with it, and if a red color comes through to the other side it may be concluded that the soil is acid. Care must be taken not to handle the end of the paper used in making the test, since the touch of the fingers may redden it." Fresh-boiled and cooled rain water is best employed for moistening the soil. If there be much carbonic acid in the soil moisture, a permanent wine-red color may be obtained; but this is not indicative of injurious acidity. If a drop of very dilute vinegar be brought upon the paper, it will give the kind of tint that an acid soil imparts, though the latter is often fainter. Any soil giving this tint needs an alkaline treatment; if the acidity is very slight, it may be temporarily corrected by use of well-rotted stable manure, but if considerable, requires the more powerful and permanent action of lime, caustic or carbonate.

### ACIDITY FROM FERTILIZERS.

It sometimes happens that an acid phosphate applied to a non-calcareous soil, or in large quantities, to one moderately rich in lime or magnesia, or upon very dry soil, or with very imperfect admixture with the soil owing to the manner of application, produces a temporary acidity in the neighborhood of the germinating seed or young cuttings, with the result that they are "burned" and often killed. On highly calcareous soils or on such as have recently received a moderate dressing of lime, such injury is far less frequent. Also, there was placed upon the market, about twenty years ago, an imperfectly prepared sulfate of potash, which was really an acid sulfate of potash; it wrought injury in the same way. There is little, if any, of this preparation now on sale, as a very simple method of preparing a safe product from the imperfect material has been discovered.

### ACIDITY CAUSED BY SELECTIVE ABSORPTION OF BASES BY PLANTS.

A third cause affecting the soil reaction is found in the power which plants possess of selective absorption of the base or acid of a salt, leaving in the soil the unabsorbed residue. There are several views as to the point at which the decomposition of the salt actually occurs, but the fact of such selective absorption is thoroughly established. This was first noted by Stohmann and, later, Kühn*

*Henneberg's Journal, 1864, pp. 116 and 135.

found that upon growing maize in solutions containing ammonium chlorid, the ammonia was absorbed, leaving a residue of hydrochloric acid in the liquid that accumulated to such strength as to kill the plants. In other cases, such as those of tri-calcium phosphate or sodium nitrate, the plant tends to use more of the acid than of the base, leaving the latter in the soil. Adolph Mayer* groups the more important fertilizer compounds according to their result upon soil reaction as follows:

*Neutral:* Calcium sulfate (gypsum), magnesium sulfate, sodium chlorid (common salt), super-phosphate and potassium nitrate.

*Acid:* Potassium chlorid (muriate of potash), ammonium sulfate, potassium sulfate and German potash salts in general.

*Basic or alkaline:* Calcium carbonate, wood ashes, caustic lime, potassium carbonate, undissolved calcium phosphate, sodium nitrate (nitrate of soda) and bone meal.

The kind of selection made varies also with the plant; thus, wheat and clover grow with roots intermixed, yet the former takes up more of silica than any other ash constituent, while clover retains little of this acid compound but accumulates the bases, lime being the most characteristic.

It must not be inferred from the foregoing statements that, given a sufficiency of food supply, the plant is wholly uninfluenced in its ash composition by the nature of the soluble materials in the soil, for all plants seem to take up, under such circumstances, an excess of the soluble salt without making any use of it in tissue formation.

## ACIDITY FROM HUMUS.

A fourth and the most general cause of soil acidity is the acid humus resulting from the decay and slow oxidation of the vegetable matter, leaves, stubble, roots, inverted sod or green manures in the soil. The formation of the common plant acids, oxalic, tartaric, citric, etc., is the result of oxidations within the plant. Sugar, starch, gums and woody matters form, under the action of oxidizing chemicals or ferments, acetic, lactic, saccharic, mucic and oxalic acids; and when the same substances are acted upon by boiling hydrochloric acid or strong potash lye, brown or black substances are formed closely resembling those that are extractible by the aid of alkalies, caustic or carbonated, from most soils, and separable from these extracts when the latter are made slightly acid. When thoroughly washed, these precipitates are found to be distinctly acid and capable of decomposing some mineral salts. The acid from dark peat is almost black in color and is called *humic acid;* that from brown peats and ordinary soils is commonly brown and is termed

*Ldw. Vers. Stat., **23**, 94-5.

*ulmic acid*; there are other more highly oxidized acids present, but more difficultly separable, known as apocrenic and crenic acids, and many others are present in minute quantities. It is very doubtful whether the true nature of these acids of the humus has yet been ascertained, since their separation in a pure state is very difficult. Fremy,* on the basis of its composition and solubility in alkaline carbonate solutions, believes humus to be derived from the ligneous matter or *vasculose*, as he terms it, of the woody tissues that have suffered incomplete oxidation in the soil. Whatever may be the true solution of its origin and constitution, these facts are clear: That the organic matters of the soil undergo a gradual oxidation whereby vegetable tissues lose all appearance of structure, acids are formed and, if conditions favor, are finally completely oxidized to form water, carbonic acid gas and certain nitrogenous compounds. If the access of air be imperfect, as when the soil is low and filled with standing water, the humus may accumulate; in cold climates this is especially the tendency, as the mossy tundras of Britsh North America, the heaths of Scotland, the moors of North Germany and the bogs of Ireland witness; but in warmer latitudes, as along the Amazon, the decay is so rapid that a few years suffices to remove all traces even of a giant tree trunk felled to earth.

In low, wet swamps and marshes where the alkaline and calcareous matters are deficient, the result is, of course, that acids form far in excess of the neutralizing power of the bases present. A similar result may occur temporarily where a heavy green-manuring crop is turned under by the plow in a non-calcareous soil or in a calcareous soil with which it is incompletely mixed from lack of proper tillage.

The free acid in such cases is not wholly composed of these humus compounds, for both humic and ulmic acid have been found by Eichhorn† to possess the power of uniting with the bases of the common neutral salts of the alkalies and alkaline earths, liberating their mineral acids; this reaction is rarely complete, however, a portion of the free acidity being directly due to humus acids.

The free acid is injurious to valuable grasses and most cultivated crops, both directly and indirectly, by affecting the bacterial life in the soil, upon which many of its desirable changes depend, and by bringing into solution poisonous ferrous compounds.

Most cultivable soils are faintly acid, owing to the presence of carbonic acid in the soil moisture, but any excess of acidity due to the four causes just considered is highly prejudicial.

### LOWLAND ACID SOILS.

Owing to the fact that marshes and swamps naturally occupy low positions and that, owing to the tendency of lime to pass by leaching

*Cf.* Dehérain, Traite de Chimie agricole, 241 *seq.*; 393.
†*Cf.* Storer, I, 482.

from the table lands and slopes to the valleys, the occurrence of decidedly acid lowland soils, even among woodlands, as Tacke* has shown, is quite rare, it has come to be generally thought among agricultural writers that soil acidity is a subject requiring little consideration.

### UPLAND ACID SOILS.

When it is recalled, however, that many soils are derived from rocks poor in lime, such, for example, as certain granites, and that the lime, even of a soil originally rich in that constituent, is sometimes almost wholly removed by leaching from an upland, it is not surprising that a careful examination of soils so situated reveals many instances of markedly injurious acidity. Thus, Muntz and Girard† mention large areas of sandy soils in Brittany, Limousin and other sections of France as distinctly acid; Schultz-Lupitz‡ states that the sandy soil in his section of Germany is deficient in lime and sour, and Ditmar§ and Hübner‖ mention the frequent acidity of sandy soils; Hilgard** has noted such acidity in the sandy uplands of the Southern States and Ruffin†† long since noted the occurrence of extensive tracts of that character in Virginia, while Wheeler and his associates have made certain the acid character of large areas of Rhode Island and Southern Massachusetts, whose soil is of granite origin.

Upon considering that the major portion of the uplands in Pennsylvania are composed of soils derived from geological formations that are not conspicuously calcareous, and also that the vegetation characteristic of many of these upland soils is made up of distinctly calcifuge plants, such as the chestnut, hemlock, etc., it may be confidently anticipated that a careful examination of these soils would reveal the existence of many tracts rendered infertile by reason of acidity.

### AMMONIA WATER TEST.

Wheeler‡‡ gives another useful test based upon the fact that ammonia water remains nearly colorless in contact with the humates or ulmates of lime and magnesia, but forms a dark colored solution, usually brown or black, when these alkaline earths are not present in sufficient quantity to neutralize the humus acids.

The test is made by introducing some of the soil to be tested into a small bottle, partially filling the latter with rain water, adding a few drops of strong ammonia water, corking the bottle, shaking and allowing the soil to settle. The reaction is not always immediate,

*See p. 64. †Les Engrais, III, 190-191. ‡Die Kalidüngung auf leichten Boden, 25. §Ldw. Vers. Stat., **14**, 277. Schulze's Lehrb. Chem. Landw. (4th ed.), 588. **X Census, V, etc.: All quoted by Wheeler, ††Rep. R. I. Agr. Exp. Sta., 1895, 232 *seq.*

‡‡R. I. Ag. Exp. Station, Bull. 46.

sometimes requiring several hours for its completion. The presence of a faint yellow color is not to be regarded; but if the tint be dark yellow, brown or black, the presence of acid humus is indicated.

### ACTION OF LIME ON MUCK SOILS.

The application of lime very quickly corrects the acidity of drained swamps and marshes, and large applications are sometimes made upon new soils of this character in fitting them for the growing of vegetables, such as onions, celery, etc. The heavy yields resulting from the action of wood ashes, derived from burning brush-heaps, upon newly cleared timber lands are, often, in part attributable to such destruction of a mild acidity. Where the practice of applying peat for fertilizing land is practised, it has long been noted that the raw or crude peat frequently works injury instead of benefit; if, however, the peat be allowed to drain and season for some months, the injurious effect is decreased. The mere weathering of the peat may result in oxidizing any sulfids and ferrous salts contained and improve its texture, but could scarcely correct its acidity; if, however, the peat be composted with lime, the acidity is promptly corrected and the compost is very soon in readiness for use.

The following pot experiment made by Johnson* shows the effect of such treatment upon the crop obtained:

| Soil. | Comparative weight of crop. |
|---|---|
| 1. Peat alone, | 1 |
| 2. Peat and ashes, | 8 |
| 4. Peat, ashes and slaked lime, | 10 |

### ACTION OF LIME ON LIGHT ACID SOILS.

Some pot experiments by Wheeler† show the relative effect of air-slaked lime, which neutralizes humus, and calcium sulfate, which has no such power. Upon light, acid soils dressed, in addition, with (a) nitrate of soda and muriate of potash and with (b) nitrate of potash respectively, the percentage of gain from the use of lime over that of the land plaster or calcium sulfate was as follows:

*Peat and Its Uses; quoted by Storer, II, 19.
†Rep. R. I. Agr. Exp. Sat., 1895, 269.

| | (a) | (b) |
|---|---|---|
| Sugar Beet: | | |
| Roots, | 207.52 | 83.15 |
| Tops, | 124.66 | 46.19 |
| Table Beets: | | |
| Roots, | 96.05 | 56.98 |
| Tops, | 30.47 | 90.99 |

Clearly, the lime had a most important effect in neutralizing the acidity, and the selective absorption exercised by the sugar beet left a considerable residue of mineral acid in the soil.

### MAGNESIA AS A NEUTRALIZING AGENT.

As for the effect of magnesia in correcting acidity, the remark of Low* that magnesian lime is especially efficient upon peaty soils may be recalled; this efficiency may arise from the fact that under favorable conditions for chemical combination, 71 pounds of magnesia can unite with as much as acid as would require 100 pounds of pure lime. Kellner† commends its efficiency as a neutralizing agent for acid soils. Dehérain‡ refers to the magnesian marls of England as reputed to possess a very special action, which is far from being explained.

Wheeler,§ in two successive years, grew mangels upon the light, acid soil of Rhode Island, to which, in addition to equal annual dressings with relatively abundant quantities of nitrate of soda and dissolved bone-black, several neutralizing agents were added together with potash salts. The pots 1 and 2 received carbonate of potash only —in 1894, 5.84 grms.; in 1895, 7.7 grms. Pots 3 to 10 received muriate of potash—in 1894, 7.36 grms. each; in 1895, 10 grms. The other distinctive characters of treatment, together with the weights of air-dried roots harvested, are shown below:

| Number. | Pots. | Alkali added. | | Yield. | |
|---|---|---|---|---|---|
| | | 1894. | 1895. | 1894. | 1895. |
| | | Grammes. | Grammes. | Grammes. | Grammes. |
| 1. | Carbonate of potash only, | ..... | ..... | 53.6 | 44.0 |
| 2. | Carbonate of potash only, | ..... | ..... | 67.1 | 58.0 |
| | Muriate of Potash Pots. | | | | |
| 3. | Caustic magnesia, | 3.81 | 3.81 | 89.9 | 100.1 |
| 4. | Caustic magnesia, | 7.62 | 7.62 | 130.0 | 126.3 |
| 5. | Carbonate of soda, | 8.3 | 8.3 | 123.4 | 131.5 |
| 6. | Carbonate of soda, | 16.6 | 16.6 | 133.5 | 131.3 |
| 7. | No alkali, | ..... | ..... | 91.7 | 51.2 |
| 8. | No alkali, | ..... | ..... | 89.7 | 91.3 |
| 9. | Air-slaked lime, | 91.98 | 18.4 | 144.2 | 148.2 |
| 10. | Air-slaked lime, | 91.98 | 18.4 | 135.8 | 132.0 |

*Cf.* p. 69.

†American Fertilizer, 6, 245.

‡*Op. cit.*, 518.

§*Op. cit.*, 265.

The conditions of moisture and food supply were such as to make the chief variable almost certainly the different neutralizing power of the several alkaline substances. The caustic magnesia is seen to have been almost as efficient as its chemical equivalent of carbonate of soda, and to fall not far below a very much larger quantity of air-slaked lime.

Upon acid soils, therefore, dressings of magnesian lime, if not made excessive in quantity, will be as effectual, if not more effectual than those of equal weights of purer limes.

### REACTION OF SOILS EXPERIMENTED UPON.

In discussing the state of combination of the lime and magnesia contained in the soils experimented upon, it was assumed* that all the carbonic acid removed from the original soils by the action of a current of carbonic acid-free air and of warm hydrochloric acid, had been present in the soil in the form of calcium carbonate. It might be inferred that since each soil yielded some carbonic acid under this treatment, all must contain calcium carbonate and, hence, none could be acid in reaction. The inference is not strictly warranted because some of the carbonic acid may have formed in the air of the soil from the oxidation of organic matter, though the conditions were not favorable to any active oxidation; it is notable that while the combined percentages of lime and magnesia varied from 0.21 to 1.58 per cent., those of carbonic acid only ranged from 0.025 to 0.048 per cent. Another ground upon which the inference may be questioned is the authority of Stockhardt† and of Mondesir‡ for the belief that small quantities of calcium carbonate may remain undecomposed in a distinctly acid soil, possibly because of the large grain of its particles or because it is not uniformly distributed.

The water-soluble acidity was determined by Mr. Beistle in the aqueous extract made by washing 20 grammes of each soil, upon a funnel, with about 100 c. c. of distilled water and titrating with very weak (deci-normal) soda solution, using phenol-phthalein as an indicator. In all but four cases, only one drop of the alkali was sufficient to neutralize the acidity, but in these cases the quantities requisite were:

| No. | Volume of alkali required. |
|---|---|
| 5, | 0.05 c. c. |
| 6, | 0.90 c. c. |
| 8, | 0.10 c. c. |
| 9, | 0.05 c. c. |

*Cf. Table VI, p. 75.
†Jb. Ag. Chem., 1866, 10.
‡Ann. Sci. Agron., 1887, **2**, 273-4.

Such a test, however perfectly it might be performed, would not suffice to show any acid constituents that are insoluble in water.

Mr. C. W. Norris applied the litmus test, using a very sensitive paper; all the soils showed some acidity, but it was decided only in cases of Nos. 5, 6, 8 and 9. A repetition some days later gave the same results. The very faint acidity is, of course, not indicative of a condition prejudicial to plant life, as has already been remarked.

The ammonia test was also applied by Mr. Norris by shaking 150 grammes (over four ounces) of the dry soil with distilled water to which a few drops of strong ammonia had been added, and noting any coloration evident a short time after the deposition of the sediment. The results were:

I. No coloration.
II. Light brown color.
III. No coloration.
IV. No coloration.
V. Decided brown color.
VI. Very deep brown color.
VII. Light brown color.
VIII. Light brown color.
IX. Light brown color.

Judging from the three tests, No. VI was strongly acid, No. V distinctly so, and Nos. VIII and IX slightly. A portion of the good results observed to follow liming on these soils must be attributed to their neutralization.

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## Influence of Lime upon the Organic Matter of Soils.

The organic matter of the soil is for the most part the partially oxidized residue from pre-existing vegetation; the composition must be, in a measure, dependent upon the kind and proportion of the ash constituents, nitrogenous bodies and woody and other carbohydrate matters of which the plants were composed, as well as upon the conditions of their decay.

### ULTIMATE COMPOSITION OF HUMUS.

This decay is accompanied by a liberation of carbonic acid, but if we may judge from the composition of the ulmic and humic acids formed artificially from sugar, the loss of carbon is less than of the other elements, for of dextrose it constitutes 40 per cent.; of humic acid, 64 per cent., and of ulmic acid, 67.1 per cent., according to Mulder.* It may be that the large proportion of carbon found in

*Cf. Johnson, How Crops Feed, 226-7.

humus is in part due to the more complete destruction of the readily fermentable substances, such as sugar, starch, etc., leaving in the residue a larger proportion of those modified celluloses—lignin bodies, hemi celluloses, cutose, etc.—which are richer in carbon than the more common and more fermentable carbohydrates. Thus, Fremy, treating wood with alkaline carbonates, extracted a group of substances separable from the extract by its acidulation. This precipitate he supposed to be one substance, with a content of 59.3 per cent. of carbon, which he termed *vasculose*. It is more readily obtained from straw than from wood.

### SELECTIVE FERMENTATIONS DUE TO LIVING ORGANISMS.

Such a selective destruction occurs in the plant itself, when deprived of its leaf food and has been observed in the curing tobacco leaf* and in the decay of sweet fruits. In all these cases, either the living plant itself or a lower organism is the effective agent in producing the bio-chemical changes observed.

The presence in the soil of numerous lower organisms, moulds or bacteria, is so thoroughly established in numerous investigations that it is sufficient here to simply affirm the fact.

### FERMENTATION OF STABLE MANURE.

The studies of Reiset,† Hebert,‡ Guyon,§ Schloesing fils|| and Dehérain** upon the changes which the straw forming the litter of stable manure undergoes during the fermentation of the manure, are highly suggestive in this connection. In brief, they found that the sugar and closely related substances of the straw are destroyed by a ferment acting in the presence of air to form carbonic acid and liberate free nitrogen, while the cellulose is destroyed by another ferment, stirred to activity whenever air is admitted, but continuing to act in its absence, which liberates some carbonic acid and more marsh gas. There is left the "vasculose" in a modified condition, partially dissolved in the alkaline liquids of the fermented manure. Upon the evaporation of this solution, a shining black substance is left containing about 40 per cent. of ash, 36 per cent. of vasculose and 24 per cent. of nitrogenous substances. The ash contains, strange to consider, phosphoric acid, lime and ferric oxid; in the absence of the organic materials these phosphates could not exist together in a neutral or alkaline liquid. The nitrogenous material too, while its

*Cf.* Rep. Penna. State College, 1894, p. 190. seq.
†*Cf.* Dehérain, Traite, 683.
‡Ann. Agron., **16**, 358.
§Comptes rendus, **98**, 528.
||Comptes rendus, **108**, 529; **109** 825; Ann. Agron. **18**, 5.
**Op. cit.*, 678 *seq.*

proportion can be diminished by repeated resolution and reprecipitation* can never be wholly dissociated.

### FERMENTATIONS OF VARIOUS SOILS DIFFER.

The nature of the changes which vegetable matters undergo by the activity of the various soil ferments has not, at least so far as the non-nitrogenous constituents are concerned, been so closely worked out as have those to which the litter of stable manure is subject. There is much reason to believe that the reaction of the soil, and possibly other conditions, exercises a very decisive influence over the kind and rate of the changes occurring within its pores. It may be true of the soil humus, as Schloesing fils found it to be of stable manure—which differed from clean litter in this respect—that change is not wholly prevented when the activity of the ferment organisms is precluded, so that it may be regarded as due in part to direct chemical action; but it is more probable that the principal agents by which fresh vegetable matter is converted into humus are fermentative or biological. The latter view leads to the expectation of dissimilarities in decomposition governed not only by climatic conditions and soil composition, but possibly also, by differences in the nature of the ferments present in different soils.

With this view of the agencies by which humus is formed, it is interesting to observe that the humus of different soils shows great variation in its solubilities, its power to support certain types of vegetation, the bacterial life present in it and the proportions of nitrogen and mineral matters closely associated with it.

### GRANDEAU'S MATIERE NOIRE.

Upon treating soils with an alkaline liquid, after a previous treatment with an acid for the removal of readily soluble basic materials, Grandeau was able to extract a portion of the humus which, upon evaporation of the solution, shows an appearance similar to the black matter extracted from stable manure by alkaline solutions; and, like the latter, this black matter of the soil—*matiere noire*, as chemists continue to call it—contains ash ingredients that do not show their presence under ordinary tests until the organic substance is destroyed by ignition, or until subjected to dialysis, which enables them to pass through a membrane that holds back the organic substance. As in the case of the stable manure, not only silica and potash, but the ordinarily incompatible substances, phosphoric acid, lime and ferric oxid are found in the associated mineral matter; while nitrogen, too, is as closely associated as in the similar manure extract.

*Cf. Ann. Agron., **14**, 116.

ITS RELATIONS TO FERTILITY.

Grandeau contends that the *matiere noire*, which is particularly abundant in *mild humus*, such as that of old garden soils, is an important solvent of the mineral matters useful as plant foods, and that the immediate fertility of a soil is in large measure determined by the amount of the mineral foods that are present in chemical combination with the *matiere noire*. This is still a debatable point, but there are many interesting facts affording some foundation for Grandeau's theory. He himself observed that the associated mineral substances in the *matiere noire* are more abundant in fertile than in sterile soil, and found them to vary from 2 to 60 per cent. of the entire extract.* Hilgard† found that in the extremely fertile "sugar-bowl dalta" lands of the Brazos River, Texas, and in the bottom lands of the Colorado River of the West, in California, the entire amount of phosphoric acid is present in the *matiere noire*, while in poor lands a much smaller fraction of the entire phosphoric acid contained was present in such combination. Snyder,‡ in analysis of certain soils from the famous wheat lands of the Red River Valley, found that the wheat yield upon those soils seems to bear a closer relation to the amount of phosphoric acid contained in the *matiere noire* than to that of any other constituent, this element of fertility showing a rapid decrease under the exhaustive system of continuous wheat culture still largely practiced in that locality.

Dehérain§ goes further, and asserts that while wheat may do without it, a certain portion of the *matiere noire* is indispensable to the best growth of clover and other legumes.

POPULAR VIEWS AS TO THE INFLUENCE OF LIME UPON HUMUS.

With this view of the nature of humus we may turn to the influence of lime upon its amount and condition. It is generally admitted from practical experience that liming often promotes the rapid decomposition of green manures, sod and peat, with the formation of a very desirable humus, but that oft-repeated, heavy liming tends, on many soils, to a final depletion of the humus supply to such a point as to seriously affect their mechanical condition and general fertility. Thus, even the surface soil of moor lands|| is brought to such a low humus content that it is needful to turn up the humus-rich subsoil in order to continue the cropping of the land.

EXACT INVESTIGATIONS UPON LOSS OF CARBON.

The exact investigations made upon loss of carbonaceous matter from humus soils show quite wide variations. The subject has

*Cf. Storer, I, 487.
†X Census, 5, 81.
‡Bulletin 53, Minn. Exp. Station.
§Ann. Agron. 9, 68; Traite, 523-4, 547.
||Cf. Heinrich, Mergel u. Mergeln, 30-31.

recently been quite elaborately discussed by E. Wollny;* after noting that dilute acids retard or prevent the decay of humus, that very dolute caustic alkali favors it, but strong solutions retard it, and that weak solutions of alkaline carbonates promote it especially, if the decay has already begun, he calls attention to the following results of investigation: E. Wolff† found that caustic lime added to fresh manure, which was then kept under cover, greatly diminished the loss, by decay, of both total organic matter and nitrogen. J. Nessler,‡ applying lime to turf and variously prepared bone-meals, found decay at first retarded, then increased, but with a total decrease from liming in the loss observed for a twelve-months' period. P. Petersen§ found the amount of carbonic acid given off from acid leaf mould greatly increased upon addition of calcium carbonate, the increase being far too great to be explained by any decomposition of the added carbonate. Wollny,|| himself, has made extensive investigations upon this subject. Addition of lime to artificial soils, the one containing as its humus material, rye straw, the other turf, found the evolution of carbonic acid diminished as the lime increased in the case of the rye straw, but increased in case of the turf. Other investigations in which turf, horse dung and humus from a sandy soil were used with different soil combinations, agreed in showing at first a decrease after liming (which is possibly due to absorption of the carbonic acid by the lime) followed by an increase, and later by a decrease; that is, while lime favors a rapid progress in the early stages of the fermentation, it has a later conservative influence.

### RELATIONS OF LIME TO MATIERE NOIRE.

A number of investigators are of the opinion that lime is a conservator of the *matiere noire*. Dehérain** notes that lime salts precipitate most, but not all, of the *matiere noire* of stable manure from solution and notes that this explains the observation of P. Thenard that while the drainage waters of recently manured sandy soils are sometimes discolored, those from calcareous soils are not. Mulder†† had earlier observed a similar precipitation of humate of ammonia (equivalent in part to Grandeau's *matiere noire*) by caustic lime and magnesia, calcium and magnesium chlorids and by ferric, ferrous and manganic sulfates. Kostycheff,‡‡ studying the causes that have led to the production of the wonderfully fertile black soil of Russia, commonly termed *tschernosem*, believes that the coloration is due to

*Die Zersetzung d. organischen Stoffe, 128-134.
†Ldw. Vers Stat., 1859, 141.
‡Ber. Arb. Grossh. Vers. St. Karlsruhe, 1870, 93-103.
§Ldw. Vers. St., **13**, 155-175.
||*Op cit.* and J. f. Ldw., 1886, 261.
**Traite, 523.
††Chem. d. Ackerkrume, quoted by Johnson, How Crops Feed, 231.
‡‡Ann. Agron. **17**, 17.

changes, in the presence of lime compounds, resulting in the formation of substances which, like the group of substances related to tannin, blacken by oxidation on exposure to the air. Hilgard* notes that lime brings about a more rapid transformation of vegetable matter into *active humus* (*matiere noire*), manifest in the deep black tint of the soil—a tint which is not present except when there is abundance of alkaline or alkaline earthy carbonate also present. He further affirms that lime protects the *matiere noire* from the oxidizing influences of a hot climate. On ordinary uplands, tending to a lime deficiency, he finds only 0.4 to 0.7 per cent. of *matiere noire;* in the more prominently calcareous soils, 1 to 1.5 per cent. or even more. He also considers that the lime materially influences the proportion of the phosphoric acid that is present in the *matiere noire;* while there are exceptions noted, as a general rule soils rich in lime contain most, and occasionally all, of their phosphoric acid in this combination, while soils poor in lime contain only one-fourth to one-tenth of their phosphoric acid in similar condition.

A. Bernard† observes that calcium carbonate unites with *matiere noire* to form a compound not soluble in ammonia until the lime be first removed by acid treatment.

On the other hand, Wollny‡ found a greater evolution of carbonic acid from a pure calcium humate than from acid humus, indicating that some, at least, of the materials present in the later stages of decomposition are not preserved from further decay by liming, but rather hastened therein. Kellner§ found an increased loss after liming both upland and paddy soil (the latter formed under conditions of submergence for part of the year), but much greater in the latter soil.

### LIMING INCREASES RETENTIVENESS OF HUMUS.

It is quite generally agreed that the liming of humus tends to increase its power to fix potash and ammonia in soils where lime has previously been deficient.‖

In our experiments a careful study was made of the amount of total organic matter and of active humus (*matiere noire*) in soils VI (muck) and VII (limestone clay) after treatment by fallowing, and by application of lime and magnesia respectively. The work upon these points was performed, upon portions of the treated soils used for the analyses previously reported, by Mr. M. S. McDowell, Assistant Chemist of the Experiment Station.

Van Bemmelen** having called attention to the fact that in the ordinary method of determining moisture by drying the soil at the

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*X Census, **5**, 77, 81; Bull. 3, U. S. Weather Bureau.
†Le Calcaire, 150.
‡*Loc. cit.*
§Bull. 9, College of Agriculture, Tokio, Japan; Exp. Sta. Record, **2**, 762.
‖*Cf.* Storer, I, 496.
**Ldw., Vers. Stat.

temperature of boiling water, other volatile matters and water of crystallization and of combination in both mineral and organic matters might be driven off, an additional determination was made of the loss of water by the soil upon suspension in a cooled bottle (temperature 3 degrees to 15 degrees C.), over sulfuric acid until the weight of the sample no longer decreased.

In addition, determinations of the total loss upon ignition and of the *matiere noire* extractible by the Huston-Grandeau* method were made. All determinations are based upon duplicate tests.

The results were as follows:

TABLE XII—Organic Matter in Air Dry Soils. (Per Cent.)

| Determinations. | Muck VI. | | | Limestone Clay VII. | | |
|---|---|---|---|---|---|---|
| | Fallow. | Lime. | Magnesia. | Fallow. | Lime. | Magnesia. |
| 1. Moisture lost at 3°-15°C, ..... | 2.13 | 1.75 | 2.08 | .36 | .29 | .27 |
| 2. Additional loss at 100°C, ..... | 3.94 | 3.35 | 3.68 | .92 | .97 | .96 |
| Total moisture (1+2), ..... | (6.07) | (5.10) | (5.76) | (1.28) | (1.26) | (1.23) |
| 3. Total loss by ignition, ..... | 21.83 | 21.75 | 22.22 | 5.36 | 5.38 | 5.49 |
| Organic Matter. (3—Total moisture), ..... | (15.76) | (16.65) | (16.46) | (4.08) | (†4.12) | (4.26) |
| 4. *Matiere noire*, ..... | 8.17 | 7.46 | 7.68 | 2.20 | 1.44 | 1.63 |
| Per cent. of organic matter present as "matiere noire," | (51.84) | (44.20) | (46.17) | (50 39) | (*34.95) | (38.26) |

*Corrected for carbonic acid lost by ignition, 36.68. †Similarly corrected, 3.92.

As to the moisture, these results seem to indicate that only a small part of the loss of weight from the air-dry soil when it is heated at the boiling point of water, is removable at the ordinary temperature in the manner previously described—the losses over sulfuric acid being, from the muck, one-third, and from the limestone clay only one-fourth of the entire loss. If it be true that the excess of loss at 100 degrees C. over that at ordinary temperature under these conditions, is due to loss of water of combination, these soils seem to have undergone a great deal of dehydration in the drying process. The subject merits an investigation with more complete checks.

It is not surprising to find the air-dry muck holding so much more water than No. VII, as that is the tendency of soils highly charged with organic materials.

The *total organic matter* has been estimated by subtracting from the percentage of loss occurring upon careful ignition, the *total moisture* lost at 100 degrees C. Admittedly this tends to give a figure too high. Not all the water of crystallization of minerals is given off at the temperature of boiling water, but the residue is expelled upon

*Proc. Assoc. Official Agr. Chem., 1895, 42.

ignition; again, complete ignition tends to dissociate any carbonates present in the soil, liberating the carbonic acid. But the amount of carbonic acid in the original material of these soils amounted to only 0.04 per cent. (*circa*), while that in the treated soils was as follows:

| | No. VI. | No. VII. |
|---|---|---|
| Lime treatment, | 0.039 | 0.202 |
| Magnesia treatment, | 0.030 | 0.068 |

So that, except in the case of the limed soil, VII, the correction for this loss would not be appreciable; but if it be assumed that all the carbonic acid was expelled in the ignition of the limed soil, No. VII, then the total organic matter will be more nearly 3.92 per cent., and the proportion of it present as *matiere noire* would be 36.68 per cent. There are no data by which a correction for the former of the two sources of error can be made.

The active humus in the original soils was earlier determined by Mr. W. S. Sweetser, then Assistant Chemist of the Experiment Station; calculated to their proportions in the water-free soil, the percentages of humus in the original and the fallow soils are:

| | VI. | VII. |
|---|---|---|
| Original, | 8.33 | 2.18 |
| Fallow, | 8.59 | 2.23 |

So that little change in this constituent appears to have resulted from the fallowing.

As for the preserving action of the two applications, it appears that in the muck soil there was less loss of total humus in the soils treated with lime and magnesia, but that there was a distinctly greater diminution of the *matiere noire*.

In the limestone clay soils, the figures for total organic matter agree too closely to warrant any distinction, but here, too, the amount of *matiere noire* was found considerably less in the soils receiving lime and magnesia. In both soils, the decrease of *matiere noire* was less with magnesia than with lime.

Under the conditions of our experiments, therefore, liming, or the application of magnesia in liberal dressings is found not to preserve but to destroy the active humus more rapidly than that which is less soluble.

## Effect of Lime upon the Nitrogenous Substances of the Soil.

### RELATIVE GAIN OF NITROGEN IN FORMATION OF HUMUS.

Kostytscheff,* in his studies of the formation of the black soils of Russia, to which reference has already been made, observed that nitrogen was lost during the decay of the plants from which the humus is, in this case, derived, much less rapidly than carbon, so that, while it amounted to only 1 to 2 per cent. of the plants, the humus contained 4 to 6 per cent.

Hilgard and Jaffa† found that this divergent tendency is magnified in arid regions as shown by the following figures:

| | Number of samples. | Humus in soil. | Nitrogen in humus. | Humic nitrogen in entire soil. |
|---|---|---|---|---|
| | | Per cent. | Per cent. | Per cent. |
| Arid soils, | 18 | .75 | 15.87 | .101 |
| Semi-arid soils, | 8 | .99 | 10.03 | .102 |
| Humid soils, | 8 | 3.04 | 5.24 | .132 |

In extreme cases they found more than 6 per cent. of nitrogen, the average in pure albuminoids, in the humus of arid soils.

Dehérain‡ states, on the basis of analyses by Boussingult, Truchot and himself, that the ratio of nitrogen to carbon in various soils ranges, in arable lands (nitrogen being taken as the unit of comparison) from 4.8 to 45.0, and in prairie or grass lands from 6.8 to 20.0, the percentage of nitrogen in the soil varying in the arable lands from 0.046 to 1.05, and in the grass lands from 0.180 to 0.940.

### CONDITION OF NITROGEN IN SOILS.

Way,§ in examining certain drainage waters, found from 2.78 to 21.05 parts of nitric acid in 100,000 parts of the water, and only from

*Ann. Agron., **17**, 17.
†Agricultural Science (1894).
‡Traité, 392.
§Jour. Roy. Soc., **17**, 133.

0.009 to 0.025 parts of ammonia. The nitric acid was more abundant than any single base.

It must not, however, be inferred from this that the soil ordinarily contains large quantities of soluble nitrogen compounds. On the contrary, the major portion is present in difficultly soluble form, despite the fact that in the leaves and stalks from which the humus is formed, much of it is present in soluble amid compounds, such as asparagin. Furthermore, the nitrogenous matter is not nearly as liable to putrefactive fermentation as are the albuminoids of plant and animal tissues.

The nitrogen of the soil has been found chiefly in three classes of compounds: in ammonium salts, in nitrates and in organic matter. But very little of it is commonly present in the first two classes of compounds. Boussingault,* for example, found in the garden soil of Liebfrauenberg, the following proportions of nitrogen in the various states of combination:

| | |
|---|---|
| Total nitrogen, ..... | 0.261 per cent. |
| Ammonia, ..... | 0.0022 per cent. |
| Nitric acid, ..... | 0.00034 per cent. |

That is, only 4 per cent. of the total nitrogen was present in the more soluble combinations. This soil, the investigator found, despite its richness in nitrogen, would not, when prevented from receiving the nitrogen compound that come in the rain, yield much more material to growing crops than the latter were able to obtain from barren soils.†

It appears then that plants must, for the most part, take their nitrogen from the soil, either in the form of ammonia or of nitric acid.

The beautiful research of Muntz‡ has shown that, in the entire absence of nitrates and of the conditions to which their formation is due, plants can take up the nitrogen they need directly from ammonium compounds.

But the great fertilizer value of the nitrates has been known since the sixteenth century, and they have been shown by the interesting researches of Berthelot and André§ to be present in all plants at some stage in their lives.

## CAUSES OF FORMATION OF AMMONIA AND NITRIC ACID IN SOILS.

There was formerly much difficulty in accounting satisfactorily by rational chemical theories for the varying transformations of the inert nitrogenous substances into the ammonium compounds and

*Agronomie, I.
†*Cf.* Johnson, How Crops Feed, 280-281.
‡Dehérain, Traite, 109-110.
§Ann. chem. phys. [6] **8**, 75-128.

nitrates. It is now known that the formation of both classes of compounds is chiefly due to the action of living organisms (bacteria) upon the inert nitrogenous substance of the soil.

Our present knowledge upon these changes is due chiefly to the investigations of Berthelot and André,* Schloesing and Muntz,† Winogradsky‡ and Warington.§ There seem to be three classes of organisms concerned in the transformations:

1. An ammonical ferment changing organic nitrogen to ammonia.
2. A nitrous ferment, converting the ammonia to nitrates.
3. And possibly a nitric ferment accomplishing the oxidation of nitrites to nitrates.

Under proper conditions for nitrification, as the conversion to nitrates is termed, the ammonia is oxidized even more rapidly than it is formed from organic matter. The conditions for favorable action are: 1. Free circulation of air in the soil. Illustrative of this condition is the recent observation of Kellner and others|| that the liming of a dry soil to which ground fish had been added induced a rapid nitrification, while in the submerged soil of the "paddy" field, the fermentation stopped with the formation of ammonia. 2. A suitable degree of moisture. 3. The presence of the active ferment. 4. The presence of a base with which nitric acid may combine as it forms, since the fermentation ceases with the appearance of acidity. 5. A temperature ranging between 40 degrees and 113 degrees Fahr.

It has been observed that in undrained marsh lands and especially in forest soils that nitrates do not form. Frank notes the great development of moulds in the forest soil and that the trees are devoid of fine absorbent root-hairs, but have the growing portions of their root systems throughly penetrated by the thin hair-like hyphae of these moulds; he suggests therefore, the probability that the moulds attack the inert organic matter and act as purveyors thereof to the trees.**

### NATURE OF INERT NITROGENOUS COMPOUNDS.

There is much uncertainty as to the real state of combination of the inert nitrogen in the humus. Johnson,†† on the basis of the behavior of this nitrogen with alkaline earths, such as lime; of the fact that albuminoids, such as are present in the plant, commonly yield amids upon decomposition, and that the reversion of ammonia to inert forms, which sometimes takes place in the soil, is most readily explained by this hypothesis, suggests the probability that the combination is of an amid nature.

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*Ann. chim. phys. [6], **11**, 375.
†*Cf.* Dehérain, Traité, 403.
‡Ann. de l'Institut Pasteur, **4**, 213.
§*Cf.* Dehérain, *Op. cit.*, 108.
||Bull. 9, College of Agr., Tohio, Japan; Exp. Sta. Rec., **2**, 764.
** *Cf.* Also Storer, I, 417-419.
††How Crops Feed, 276-280.

## INFLUENCE OF LIME ON SOIL AMMONIA.

Concerning the effect of lime upon the nitrogenous constituents of the soil: It is common laboratory experience that on the addition of caustic lime or carbonate of lime to solutions of ammonium salts, at ordinary temperatures, ammonia is liberated.

A. Bernard* finds, that upon application of ammonium sulfate to soils containing no more than 1 per cent. of lime, a liberation of ammonia occurs in from five to ten minutes.

It is probable that ammoniacal fermentation of the soil is promoted by the presence of calcium carbonate; but an excess of the caustic lime would tend to be injurious to the ferments. Ladureau† observed that the addition of lime to a 2 per cent. solution of urea retarded the action of the ammonicial ferment in proportion to the amount of lime introduced.

## LIME AFFECTS NITRIFICATION.

As to the influence of lime compounds on nitrification: Touvenal‡ long since observed that the formation of nitre in nitre-beds is most favorably affected by the use of chalk and pure carbonate of lime. But quick-lime he found to be much less useful. Boussingault§ found that caustic lime caused a loss of ammonia from garden soil and a hindrance of nitrification. Indeed, an excess of it in the presence of moist earth may induce putrefaction and a consequent destruction of nitrates. Warington|| found that lime water was twice as strongly alkaline as is desirable for the best development of the nitric ferment. Very heavy limings have been observed to materially reduce the richness of vegetation of a soil for the first year, but to conduce to a rankness of growth thereafter, indicating that the lime had meanwhile been converted from the caustic into the carbonated form. Bernard, therefore, suggests that it is dangerous to apply caustic lime to an already calcareous soil, and Wollny** cites experiences of Pichard,†† Warington‡‡ and Dumont and Crochetelle§§ to the effect that where there is already a tendency to alkalinity, applications of sulfate of lime or of potash would be more helpful than even the corresponding carbonates.

On the other hand, Bernard|| || notes that on non-calcereous soils, organic materials, even those so readily nitrifiable as dried blood, often fail to show markedly beneficial results and require, in the

*Le Calcaire, 68-75.
†C. R. **99**, 887.
‡*Cf.* Storer, I, 301.
§Storer, *Loc. Cit.*
||Ann. agron., **14**, 49.
***Op cit.*, 136.
††C. R. **89**, 1289 **114**, 490.
‡‡Ann. agron., **14**, 557.
§§C. R., **117**, 670.
|| ||*Op. cit.* 76-87.

absence of liming, direct applications of nitrates or ammonium salts to supply the requisite nitrogen. Muntz and Girard* observes that the distinctly acid soils of Brittany and also the non-calcareous soils of Limousin set up little nitrification in added fertilizers unless the latter can supply the requisite alkali.

Kellner has observed that magnesia affects nitrification favorably, but Winogradsky was led to prefer lime compounds instead of the magnesium salts he earlier used in his culture fluids for the nitrifying bacteria.

## NITROGEN DETERMINATION IN SOILS.

The observations upon the changes which the nitrogen in the several soils experimented upon, underwent as the result of the several treatments, were confined to Nos. VI and VII.

In addition to the determinations of moisture, organic matter and active humus already discussed, there were determined:

1. Total nitrogen by the official Scovell-Kjeldahl method, working upon 2 g. of No. VI and 20 g. of No. VII.

2. Nitric and ammoniacal nitrogen combined, using the official Ulsch-Street method, working upon 20 g. of the soil.

3. Ammoniacal nitrogen: 20 grammes of the soil were distilled under reduced pressure with caustic magnesia; enough of the reagent was used to make the liquid distinctly alkaline, 5 g. being the usual amount. It is well known that the accuracy of the method is impaired by the tendency of amids, if present, to liberate their nitrogen in the form of ammonia, when brought into contact with alkaline earths, lime being more powerful than magnesia. It has been suggested that under reduced pressure, the latter reagent will not effect so extensive decomposition.

Under my direction, Mr. W. S. Sweetser distilled various amid substances at ordinary pressures and at a pressure so reduced that the boiling point of the liquid ranged from only 32 degrees to 38 degrees C. The amounts of ammonia found in the distillate are expressed in terms of their equivalent of decinormal ammonia solution (3.5 g. ammonium hydrate to the litre). O. P.=Ordinary pressure; V.=In vacuo:

TABLE XIII—Liberation of Ammonic from Organic Substances upon Distillation.

| | Cubic centimeters of N-10 ammonia equivalent. |
|---|---|
| 250 distilled water with 5 g. caustic magnesia, | 0.1 |
| .10 g. urea, in distilled water (O. P.), | 1.8 |
| .10 g. urea, in distilled water (V.), | 1.7 |
| .10 g. urea, in distilled water with 5 g. caustic magnesia (O. P.), | 2.0 |

*Ann. agron., **17**, 297.

| | Cubic centimeters of N-10 ammonia equivalent. |
|---|---|
| .10 g. urea, in distilled water with 5 g. caustic magnesia (V.), | 0.4 |
| .10 g. uric, acid, in distilled water with caustic magnesia (V.), | 0.6 |
| .20 g. asparagin, in distilled water (V.), ..... | 0.5 |

Some loss occurs even on boiling in pure water at reduced pressures; caustic magnesia did not appreciably increase this loss.

4. Humus nitrogen was separately determined in an aliquot portion of an extract prepared by the Huston-Grandeau method, except that 3 per cent. caustic soda instead of 4 per cent. ammonia water was used as the solvent; the Kjeldahl method of nitrogen determination was used.

5. There are present in the soil several types of amid bodies. Some of these, being acid amids, give up their ammonia when heated with a strong acid. To estimate the nitrogen in this state of combination, 100 g. of the soil was suspended in 500 c. c. of water, containing 15 g. of strong hydrochloric acid, and kept upon a water-bath for forty-eight hours. The total nitrogen in an aliquot of the carefully filtered liquid was determined and the amid nitrogen estimated by subtracting from the amount of nitrogen thus found, the sum of the nitric and ammoniacal nitrogen. It is not sure that all the acid-amid nitrogen it recoverable under these conditions, but is believed that most of it should be.

Attempts were also made to separate the nitrogen present in form of amido acids, if any, by treatment with nitrous acid; but thus far we have not succeeded in preparing a satisfactory working method for such materials. The determinations in the original soil were made by Mr. W. S. Sweetser; in the treated soils by Mr. M. S. McDowell. The results obtained are given in terms of the water-free soil.

TABLE XIV— Nitrogen in Original and Treated Soils. (Per Cent. of Water-Free Soil.)

| Determination. | Muck. (No. VI.) | | | | Limestone Clay. (No. VII.) | | | |
|---|---|---|---|---|---|---|---|---|
| | Original. | Fallow. | Lime. | Magnesia. | Original. | Fallow. | Lime. | Magnesia. |
| Loss by ignition (total organic matter), | ..... | 23.24 | 22.92 | 23.58 | ..... | 5.44 | 5.46 | 5.56 |
| Humus (matiere noire), | 8.33 | 8.59 | 7.86 | 8.15 | 2.18 | 2.23 | 1.46 | 1.65 |
| Total nitrogen, | .578 | .618 | .595 | .597 | .116 | .130 | .125 | .119 |
| Ammoniacal nitrogen, | .0134 | .0053 | .0003 | .0042 | .0027 | .0024 | .0013 | .0010 |
| Nitric nitrogen, | .0310 | .0341 | .0474 | .0419 | .0125 | .0134 | .0167 | .0201 |
| Amid nitrogen, | .2657 | .2938 | .2537 | .2467 | .0379 | .0467 | .0458 | .0347 |
| Other organic nitrogen, | .2679 | .2848 | .2936 | .3042 | .0629 | .0675 | .0612 | .0632 |
| Nitrogen in Humus. | | | | | | | | |
| a. Per cent. of entire soil, | .4012 | .3705 | .2929 | .2950 | .0824 | .0558 | .0486 | .0456 |
| b. Per cent. of humus, | 4.82 | 4.26 | 3.73 | 3.62 | 3.78 | 2.50 | 3.29 | 2.76 |
| Proportion of Total Nitrogen in the Several Nitrogenous Compounds. | | | | | | | | |
| Ammoniacal, | 2.32 | .86 | .05 | .71 | 2.29 | 1.80 | 1.06 | .85 |
| Nitric, | 5.37 | 5.52 | 7.96 | 7.02 | 10.83 | 10.39 | 13.41 | 17.35 |
| Amid, | 46.00 | 47.59 | 42.62 | 41.30 | 32.75 | 35.94 | 36.79 | 29.23 |
| Other organic compounds, | 46.31 | 46.03 | 49.37 | 50.97 | 54.13 | 51.87 | 48.74 | 52.57 |
| (Humus), | (69.47) | (60.00) | (49.20) | (49.38) | (71.10) | (42.97) | (39.02) | (38.46) |

It is to be remembered that here, as in preceding cases, the results reported are averages of several closely agreeing determinations, and that the sub-sample representing the "original" soil probably differs more from those representing the results of the several treatments than do the latter from each other.

A direct comparison of the *original* and *fallow* soils is not possible, but some conclusions of value may be had from a comparison of the proportions in which the nitrogen is represented in the several classes of compounds in the two sets of samples.

In both the muck and limestone clay there is a smaller proportion to the total nitrogen present in ammoniacal combination. In the muck, there is a little more present in nitric compounds, but in the clay considerably less.

There is more nitrogen present in amid combination, whether by reason of a primary formation of ammonia and its subsequent fixation in that form, or by direct transformation of other nitrogenous organic compounds, it is, of course, not possible to judge.

More of the nitrogen than is represented in the amid compounds is found in the active humus. The proportion of the total nitrogen present in the active humus is less in the fallow soil than in the original untreated sample. Evidently the fermentative changes occurring during the fallowing have resulted in making the nitrogenous substances of the organic matter relatively less soluble in alkaline liquids. This retrogression is particularly observed in the cultivated limestone-clay soil.

Comparing more closely the figures for the fallow and soils receiving lime and magnesia respectively, these facts appear:

The total nitrogen in the soil is slightly diminished in the limed soils and those receiving magnesia; this may possibly be due to a loss from the ammoniacal compounds, which are less in their residual amount in both lots of soil representing the effects of these treatments than they are in the fallow samples.

The nitrates are more abundant, very considerably so, where the alkaline earths were applied. In the muck, the magnesian treatment showed less nitrates; in the limestone-clay, more nitrates than the lime treatment.

In both cases there was also a marked decrease in the nitrogen present in amid condition, far greater than the increase of nitrates can counter-balance; in other words, whether by reason of appropriation in the organism of the ferment present or by simple chemical change, the nitrogen appears to have reverted in part to an even less readily decomposable form than the amid compounds. This was particularly true of the muck soil.

In both cases, also, the "matiere noire" contains more nitrogen

than is accounted for by the amid compounds simply. The data afford no information by which we may judge whether the amids are entirely extracted in the "matiere noire" or not. If they are, the residual nitroneous organic substances may be further sub-divided into two groups: That portion soluble as "matiere noire," and that part insoluble in the alkaline solvent.

It is observable, further, that the "matiere noire" from the limed soils is slightly richer in nitrogen than that from the magnesian treatment.

In general, the effect of both alkaline earths was to diminish the active humus, and the nitrogen, particularly that present as ammonia, and to increase the nitrates. While lime acted somewhat more vigorously than magnesia in the two particulars first named, there is no certain indication as to which was the more potent in favorably influencing the process of nitrification.

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## EFFECT OF LIMING UPON THE CHARACTER OF THE VEGETATION GROWING UPON THE TREATED SOIL.

It has been a matter of almost universal remark in localities where liming is practised, that its use is followed by a very marked change in the character of the vegetation, particularly in the quality and kind of cultivated crops and forage plants that the soil produces.

### CLOVERS, GRASSES AND SORRELS.

The reports of correspondents from various portions of this State remark upon the greatly improved growth of forage plants, including the valuable grasses, but especially white and red clovers, after the application of lime; also, upon the disappearance of horse sorrel (red top," as it is called in some localities of the State) and of wild blackberries and dewberries.

Heinrich* notes the marked differentiation of the plants upon the same soil, on tracts that have been limed as compared with tracts not limed. He says: "In trials made upon a soil deficient in lime, one portion of which was limed, while another received a dressing of nitrate of soda, both receiving equal quantities of mixed clover and grass seed, the appearance was as though one part (that which was limed) had been seeded only with clover, the other only with grasses.

*Mergel u. Mergeln, 6.

Closer examination showed that both kinds of plants were present in each case, but that the plant most affected by the particular fertilizing material used, in each case, crowded out the other plants. To secure a mixed forage it is, therefore, not enough to seed with a proper seed mixture, it is needful to see that the chemical composition of the soil is such as is adapted to the several plants."

Flagg, Wheeler and Tucker* separated the several portions of the hay cut from plats that had received different treatments, and that were laid out upon the upland, granitic sandy soil of the Rhode Island Station upon which sorrel grows luxuriantly; they obtained the following portions by weight from areas two feet square:

| Treatment. | Clover. | Sorrel. | Timothy. | Miscellaneous weeds. |
|---|---|---|---|---|
| | Lbs. | Lbs. | Lbs. | Lbs. |
| No nitrogen—limed, | 3.26 | 0.06 | 0.00 | Trace. |
| No nitrogen—unlimed, | 0.00 | 1.35 | Trace. | 0.05 |
| Dried blood—limed, | 3.00 | 1.00 | 0.09 | 0.00 |
| Dried blood—unlimed, | Trace. | 0.95 | 0.00 | 0.05 |
| Nitrate of soda—unlimed, | Trace. | 0.70 | Trace. | 0.00 |
| Sulfate of ammonia—unlimed, | 0.00 | 3.50 | 0.00 | Trace. |

The almost entire absence of timothy in all cases is rather surprising, but the good effect of liming upon the clover yield is well shown. The authors says: "It appears probable that the chief value of lime in eradicating sorrel is attributable to the fact that it brings about physical and chemical soil conditions, one or the other or both of which, are so highly favorable to the growth of clover and many other agricultural plants that they are able to occupy the land, thereby preventing sorrel from gaining a foothold."

The writer has frequently observed a very striking growth of sorrel upon patches of land, the clover and timothy upon which have failed to make a catch, though in other seasons the same land shows very little sorrel, the season having favored a good stand of the grass seed.

Careful surveys of the several plats used in the rotation fertilizer experiments of the Pennsylvania Experiment Station have repeatedly shown the same phenomenon, and have further shown the predominance of clover over timothy on the plats receiving lime, ground limestone or land plaster as compared with those dressed with acidu-

*Rep. R. I. Agr. Exp. Sta., 1895, 193-199.

lated phosphates and nitrogen, the timothy predominating, however, on the latter.

Voelcker* says: "Every (British) farmer knows how essential lime is for the healthy growth of very kind of produce. On soils destitute of lime, most crops, and especially green crops, are subject to disease, and "root crops" are apt to fail altogether on such land, even if it has been liberally manured with dung or guano. Up to a certain stage, grain and roots grown under such conditions appear to thrive well, but as the season advances they sustain a check, and at harvest time yield a miserable return. The cure for such failures, which are not uncommon where poor sandy soils prevail, is a good dose of lime or marl, and then, and only then, dung or guano may be applied to the greatest advantage. The most liberal application of farm-yard manure of the best quality never produces so beneficial and lasting an effect on poor sandy soils as when they have been previously well marled or limed."

P. Pichard,† in reference to the sandy soils of Brittany which are rich in humus but poor in lime and potash, says: "The application of lime raised the yield of fodder beets from 6,315 kilograms to 21,627 and 38,700 kilograms per hectare, or, in other words, the yield was quadrupled and sextupled. An addition of plaster still further increased the yield."

Dehérain‡ says: "There are certain of the principal field crops, notably the legumes, which are so highly benefitted by the presence of lime that liming alone on grass lands, where calcareous matter is deficient, is all that is needful to secure a spontaneous growth of clover, the seeds brought there by the wind prospering as soon as the soil is made favorable to it."

"Limousin had been for ages a miserable land, and it was not transformed nor brought to the state of relative prosperity which it now enjoys until the time when the construction of a railroad allowed the introduction, at low cost, of lime from the Departement du Cher; the culture of clover, unknown until now in this granitic country, has become possible, more numerous and better fed domestic animals now supply enough manure to convert the thin pastures into productive grass lands; the food for an excellent race of Limousin beef being assured, its breeding has made rapid progress and the sale of the young animals has become a source of large profit to both land owners and tenants."

"In moist grass lands the use of lime has a remarkable effect; I have more than doubled the yield from the grass lands of l'Avre, belonging to the city of Paris, by treating them with lime or plaster, in addition to a small quantity of nitrate of soda."

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*Quoted by Storer, II, 147.
†C. R., **119**, 473.
‡Traité, 531.

Heinrich* says: "Potatoes and rye grow well even when the soil is too poor in lime for other crops. Large yields may still be obtained from soils, particularly when they are well cultivated, even though their lime content has fallen to 0.05 per cent."

"Oats and barley have a somewhat higher lime requirement than rye and potatoes."

"Peas and vetches grow quite well upon a soil having 0.10 per cent., but fail entirely upon poorer soil."

"Red clover yields well with 0.1 to 0.12 per cent.; with less than 0.1 per cent., it fails completely, and yields best when the soil contains at least 0.2 per cent. of lime."

"Of all crops, alfalfa responds best to lime."

On the other hand, he says:† "Lime as calcium carbonate injuriously affects the growth of lupins when it is present to the amount of 0.46 per cent."

Wheeler and Tucker‡ have conducted, for several years, comparative tests of the growth of a great variety of plants upon soils receiving each year a basal mixture of dissolved bone-black, muriate of potash and nitrate of soda, and, in 1895 and 1896, 200 lbs. per acre of sulfate of magnesia; part receiving no lime, the rest 5,400 lbs. per acre in 1893, 1,000 lbs. per acre in 1894, none in 1895. The relative yields from the limed soil for the several years are given below, the corresponding yield on the unlimed soil being taken as 1:

Yields of Various Plants after Liming.

| | 1893. | 1894. | 1895. | 1896 |
|---|---|---|---|---|
| **Grasses.** | | | | |
| Awnless Brome Grass, | ..... | ..... | 1.55 | 1.21 |
| Kentucky Blue Grass, | ..... | ..... | 1.20 | 1.21 |
| Meadow Fox-tail, | ..... | ..... | 1.30 | ..... |
| Meadow Oat Grass, | ..... | ..... | 1.09 | 1.16 |
| Orchard Grass, | ..... | ..... | 1.16 | ..... |
| Red Top, | ..... | ..... | 1.17 | 0.94 |
| Rhode Island Bent, | ..... | ..... | 0.99 | 1.18 |
| Sheep's Fescue, | ..... | ..... | 0.00 | 1.51 |
| Soft Grass, | ..... | ..... | 1.01 | 1.17 |
| Sweet Vernal, | ..... | ..... | 0.89 | ..... |
| Tall Fescue, | ..... | ..... | 1.24 | ..... |
| Timothy, | ..... | ..... | ..... | 1.22 |
| **Leguminous Forage Crops.** | | | | |
| Alfalfa (1st crop), | ..... | ..... | 3.68 | ..... |
| Alfalfa (2d crop), | ..... | ..... | 1.49 | ..... |
| Bean, Soja, | ..... | 1.06 | ..... | ..... |
| Bean, White Podded Adzuki, | 0.82 | 0.88 | ..... | ..... |
| Blue Lupine, | 0.47 | 0.23 | 0.61 | 0.77 |
| Cow Pea, | 0.80 | 0.94 | ..... | ..... |
| Clover, Crimson, | 1.35 | ..... | ..... | 1.59 |
| Clover, Red, | ..... | 1.70 | ..... | ..... |
| Serradilla, | ..... | ..... | 0.69 | ..... |
| **Millets.** | | | | |
| Panicum cruss-galli, | 1.31 | ..... | 0.82 | ..... |
| Golden, | 1.04 | 0.87 | ..... | ..... |
| Hungarian, | 0.91 | ..... | ..... | ..... |
| Itallan, | 0.87 | ..... | ..... | ..... |
| German, | ..... | 0.90 | ..... | ..... |

*Mergel u. Mergeln, 7.

†*Op. cit.*, 63.

‡R. I. Agrl. Exp. Sta., Bulletin 46, pp. 97-100.

Yields of Various Plants after Liming—Continued.

| | 1893. | 1894. | 1895. | 1896 |
|---|---|---|---|---|
| **Grains.** | | | | |
| Barley, | 1.80 | 2.06 | 3.58 | 2.56 |
| Buckwheat, | 1.65 | 1.53 | ..... | ..... |
| Corn, Dent, | 1.17 | ..... | ..... | ..... |
| Corn, White-capped, | 0.71 | ..... | ..... | ..... |
| Corn, Pop, | 1.56 | ..... | 1.03 | ..... |
| Corn, Sweet, | 2.07 | 1.11 | 1.89 | ..... |
| Corn, Field, | ..... | 0.61 | 1.06 | ..... |
| Oats, | 1.26 | 1.09 | 1.07 | ..... |
| Rye, Spring, | 1.13 | 1.03 | 0.75 | 1.33 |
| Wheat, Spring, | ..... | 1.40 | 1.91 | ..... |
| **Vegetables.** | | | | |
| Bean, Common White, | 0.94 | 0.88 | ..... | ..... |
| Bean, Golden Wax, | ..... | 1.58 | ..... | ..... |
| Beet, French Sugar, | 12.17 | 11.00 | ..... | ..... |
| Beet, Golden Tankard, | 10.75 | ..... | ..... | ..... |
| Beet, Eclipse Table, | 7.78 | 5.35 | 1.84 | ..... |
| Beet, Mangel, Long Red, | 7.59 | 5.77 | ..... | ..... |
| Beet, Mangel, Globe, | ..... | 8.21 | ..... | ..... |
| Beet, Mangel, | ..... | ..... | 4.95 | 5.73 |
| Brussels Sprouts, | ..... | 1.57 | ..... | ..... |
| Cabbage, Late, | 2.37 | 4.60 | 1.70 | ..... |
| Cabbage, Early, | 1.28 | 1.24 | ..... | ..... |
| Carrot, Victoria, | 1.78 | ..... | ..... | ..... |
| Carrot, Mastodon, | 1.76 | ..... | ..... | ..... |
| Carrot, Long Orange, | ..... | 0.87 | ..... | ..... |
| Carrot, Danvers, | ..... | 0.74 | ..... | ..... |
| Carrot, White, | ..... | 1.18 | ..... | ..... |
| Carrot, | ..... | ..... | 1.96 | 6.67 |
| Cauliflower, | ..... | 3.70 | ..... | ..... |
| Celery, | ..... | 9.42 | 27.60 | ..... |
| Cucumber, | ..... | 3.02 | ..... | ..... |
| Dandelion, | ..... | 1.08 | 1.74 | 2.33 |
| Egg Plant, | ..... | 3.75 | ..... | ..... |
| Gumbo, | ..... | 11.38 | ..... | ..... |
| Kale, | 1.51 | 1.15 | ..... | ..... |
| Kohl Rabi, | ..... | 1.59 | 1.60 | ..... |
| Lettuce, | 77.93 | 10.00 | ..... | ..... |
| Martynia, | ..... | 2.84 | ..... | ..... |
| Muskmelon, | ..... | 4.70 | 2.45 | ..... |
| Onion, Red, | ..... | 9.00 | ..... | ..... |
| Onion, Yellow, | ..... | 8.12 | ..... | ..... |
| Onion, Barletta, | ..... | 7.88 | ..... | ..... |
| Onion, Egyptian, | ..... | 31.00 | ..... | ..... |
| Parsnep, | ..... | 6.99 | ..... | ..... |
| Pea, Granger, | 1.53 | ..... | ..... | ..... |
| Pea, Garden, | ..... | 1.65 | ..... | ..... |
| Peanut, | ..... | 2.53 | ..... | ..... |
| Pepper, | ..... | 2.74 | ..... | ..... |
| Potato, Early Rose, | 1.03 | 1.05 | ..... | ..... |
| Potato, Beauty of Hebron, | ..... | 1.67 | ..... | ..... |
| Pumpkin, | ..... | 0.55 | 5.36 | ..... |
| Radish, Long Scarlet, | ..... | 1.37 | ..... | ..... |
| Radish, French Breakfast, | ..... | 0.87 | ..... | ..... |
| Salsify, | ..... | 9.50 | ..... | ..... |
| Spinach, | 24.75 | 61.00 | ..... | 20.50 |
| Tomato, | 1.40 | 1.42 | ..... | ..... |
| Turnip, Ruta Baga, | 1.58 | 1.46 | ..... | ..... |
| Turnip, Purple Top, | ..... | 1.29 | ..... | ..... |
| Turnip, Early Red Top, | ..... | 1.15 | ..... | ..... |
| Turnip, Flat, | ..... | ..... | 1.34 | ..... |
| Watermelon, | ..... | 0.64 | 0.55 | ..... |
| **Miscellaneous Plants.** | | | | |
| Gladiolus, | ..... | ..... | ..... | 0.87 |
| Jerusalem Corn, | 2.41 | ..... | ..... | ..... |
| Kaffir Corn, | 3.40 | ..... | ..... | ..... |
| Rape, | ..... | 1.97 | ..... | ..... |
| Sorghum, | 10.59 | 2.99 | ..... | ..... |
| Sorrel, | ..... | 0.36 | 0.82 | ..... |
| Sunflower, | 1.09 | 1.42 | ..... | ..... |
| Tobacco, | ..... | 4.52 | ..... | ..... |

Almost without exception the grasses have shown benefit from liming; among the millets, in only two cases out of seven; among the grains, barley, buckwheat and wheat have shown much more benefit than corn (with a curious exception in the case of sweet corn), oats or rye; among the leguminous forage crops there is a very strange

contrast, already noted by Heinrich and others: while the clovers and alfalfa exhibit a very marked advantage from liming, the soja bean shows none and the blue lupine, serradella, cow pea and white podded adzuki bean show most marked injury. Among the vegetables there was a very general improvement, except in the case of the watermelon and of some specimens of pumpkin, carrot and radish; beets, celery, gumbo, lettuce, onions and spinach were most advantageously affected. Among miscellaneous plants, sorghum and tobacco were most favorably, horse sorrel and the gladiolus unfavorably affected.

Salfeld* and Wheeler† incline to the opinion that the injury to the lupine and other legumes is not direct, but rather upon the minute organisms forming the nodules on the roots of such plants.

## INFLUENCE UPON INSECTS AND INJURIOUS FUNGI.

Concerning its influence on hurtful insects and fungi, Storer‡ says: "Slaked lime is regarded as a cure for some hurtful fungi. The liming of seed grain to destroy the fungus which causes 'rust,' or 'smut,' has long been usual. The use of lime upon turnips, as check to the finger-and-toe disease has been mentioned; and I can myself bear witness that I have grown exceptionally fair and smooth rutabagas during three consecutive years upon limed land at the Bussey Institution, though no farmer in the vicinity would venture to try to grow turnips year after year on any one field, because of their liability to the disease called 'club foot.' * * It is not improbable * * * that some part of the good done by the lime may be due to the destruction of insects and their larvae, as well as earth-worms and worms of other kinds, and fungi of various sorts. Indeed, lime-water, lime and mixtures of lime and salt (or, better yet, of lime and muriate of potash) are often purposely used by gardeners for destroying slugs and worms; and there are good reasons for believing that lime might often be applied to the soil with advantage in farming practice also on this account."

The voluminous literature of the American Experiment Stations state many observations in confirmation of Storer's opinion, though lime cannot be regarded as an universally applicable remedy. The

*Die Boden Impfung, pp. 79-83.
†Bull. 46, R. I. Exp. Sta., 92.
‡*Op. cit.*, II, 147-8.

lime absolutely favors the potato scab fungus, and potatoes grown on limed soil from scabby seed are usually very greatly roughened by the exceptionable growth of the scab under such conditions.

Does the lime act in the soil in the caustic or in the carbonated form?

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## LIME SUPPOSED TO ACT CHIEFLY AS CARBONATE.

There is considerable doubt upon the above question. Recognizing the general tendency of lime to take up carbonic acid promptly by the process of air-slaking and considering the fine sub-division of the slaked lime as it reaches the soil, and the facts that the air of the soil is commonly much richer in carbonic acid than is the general atmosphere and that the fermentative destruction to which the humus and other organic matters of the soil are increasingly subjected through the influence of the added lime, must temporarily tend to a still greater proportion of carbonic acid in the soil air, it is generally conceded that the lime must be carbonated almost immediately after it is spread and harrowed in.

Storer* says: "It is not to be supposed that, in the field, reactions due to the causticity of the lime can go on for any long period." He then gives reasons, similar to those of the preceding paragraph, for this belief. "The action of the carbonate of lime, when formed, will not differ essentially from that of marl, or powdered limestone."

Mayer† also makes a very similar statement.

### INFLUENCE OF FINENESS OF CARBONATE.

R. Heinrich,‡ going upon the above theory, claims that the lime changes almost immediately after its application to the soil, to the carbonate; the greater effect of burnt lime, as compared with pulverized chalk, limestone and other lime carbonates, is supposed to be due not to its causticity, but to the finer sub-division of the carbonate which is formed from it. To show the influence of fineness upon the effective action of calcium carbonate, this investigator grew peas and alfalfa in a series of pots; the sandy soil used contained only 0.091 per cent. of lime; the pots in most of the series received a basal manure containing potash and phosphoric acid, and four sets received a further addition of finely pulverized Carrara marble, of different degrees of fineness, graded by sifting, the quantity added in each instance being equal to 0.5 per cent. of the weight of the soil. Letting the maximum yield be represented by 100, the several crop yields were relatively as follows:

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*Op. cit., II, 151.
†Lehrb. Agr. Chem., II, 286.
‡Mergel u. Mergeln, 29.

| Treatment. | Peas. | Alfafa. |
|---|---|---|
| Unfertilized, | 54.2 | 0 |
| Basal fertilizer alone, | 47.1 | 0 |
| Fertilizer and marble, grains 1.5 to 2 mm. diameter, | 66.7 | 59.2 |
| Fertilizer and marble, grains 1.0 to 1.5 mm. diameter, | 80.1 | 78.5 |
| Fertilizer and marble, grains 0.5 to 1.0 mm. diameter, | 90.2 | 100.0 |
| Fertilizer and marble, grains less than 0.5 mm. diameter, | 100.0 | 100.0 |

In other words, the carbonate in grains of 0.06 to 0.08 inches diameter, was scarcely more than half as efficient as that of about half that diameter, the surface exposed to the action of solvents being four times greater in the latter case, assuming an equal distribution of the particles in each case.

A. Bernard* suggests that the efficiency of the lime compound depends not solely upon its nature and fineness of sub-division, but also upon the relation between its effective surface and that of other soil constituents present; thus clay, being more finely divided than sand, would more largely modify the action of the lime than would sand.

COMPARATIVE EFFECTS OF CAUSTIC AND CARBONATED LIME.

It is further asserted that in many ways the actions of the caustic lime and the carbonate are almost precisely alike.

Thus, to test their relative efficiency in liberating alkalies from a soil, Heinrich† exposed 200 grammes of soil and of mixtures of the soil with caustic lime and calcium carbonate in quantities equivalent to 0.5 per cent. of calcium oxid for each 100 parts of soil. Water to the amount of 750 c. c. was used, and where carbonic acid was employed it was led into the liquid, already mixed with the soil, for one hour at the beginning of the period of twenty-four hours, during which the solvent acted in each case. The results are expressed in the weight of alkaline sulfates found in the liquid for each 100 grammes of soil used:

| Treatment. | Weight of alkaline sulfate. Grammes. |
|---|---|
| 1. Pure water, | 0.031 |
| 2. Pure water with carbonic acid, | 0.038 |
| 3. Pure water with caustic lime, | 0.048 |
| 4. Pure water with caustic lime and carbonic acid, | 0.066 |
| 5. Pure water with carbonate of lime, | 0.046 |
| 6. Pure water with carbonate of lime and carbonic acid, | 0.060 |

*Le Calcaire, 59-62.

†*Op. cit.*, 29.

That is, the caustic lime and the carbonate were of equal effectiveness under like conditions of action.

Dietrich* had, much earlier, made a similar investigation, exposing soils and pulverized rocks for three months to the action of distilled water with (1) caustic lime, (2) calcium carbonate, (3) calcium carbonate and carbonic acid. Two hundred grammes of the material, from which readily soluble matter had first been removed by repeated washing, were used with 150 c. c. of water; the lime used equalled 1 per cent. of the soil, the calcium carbonate 2 per cent. The carbonic acid was added to saturation and four times renewed during the experiment. The alkalies made soluble are expressed as chlorids, in grammes:

| Material. | Caustic lime. | Calcium carbonate. | Calcium carbonate and carbonic acid. |
|---|---|---|---|
| | Grammes. | Grammes. | Grammes. |
| Basalt, freshly broken, moderately fine, | 0.144 | 0.057 | 0.154 |
| Porphyry, | 0.009 | Trace. | 0.011 |
| Loam rich in humus, | 0.022 | 0.014 | 0.023 |
| Loam rich in humus, burned, | 0.024 | 0.029 | 0.025 |

In this experiment, the carbonate was markedly inferior, except in case of the burned loam; with the aid of carbonic acid, however, its action was equal to that of the caustic lime. There is no satisfactory information concerning the fineness of the carbonate, however, so that the inferior action of the latter may be due to its coarseness rather than to its chemical inactivity.

The sulfate is said to be more potent than caustic lime in converting anhydrous silicates to the more available forms.

It has already been observed that the mild carbonate of lime is readily attacked by humus acids, so that it serves well the purpose of correcting soil acidity; also, that it more favorably affects nitrification than does caustic lime; and, very possibly, the same may be true of the other bacterial actions constantly occurring in the soil. Furthermore, if, as some aver, the flocculating action of lime be really due to a solution of acid calcium carbonate, the carbonate should equally well promote the improvement of heavy clay soils.

To secure more direct testimony as to the eventual net result of the various reactions set up in the soil by the application of lime in the caustic or the carbonated condition, Henirich† carried on an ex-

*J. prak. Chem., **74**, 12; Jb. Agr. Chem., **1**, 34.

†*Op. cit.*, 23.

periment, using the same soil and basal manure as were employed by him in the previously described experiment made to determine the influence of the fineness of the carbonate upon its efficiency. In addition to the basal manure, enough of the several calcareous compounds was added to furnish calcium oxid equivalent to 0.5 per cent. of the soil. The relative weight of peas and alfalfa secured are given below, 100 standing for the maximum:

| Treatment. | Peas. | Alfafa. |
|---|---|---|
| 1. No fertilizer, | 47 | 0 |
| 2. Basal fertilizer, | 41 | 0 |
| 3. Marly loam from Lupitz (contains 8.46 per cent. lime), | 79 | 97 |
| 4. Commercial precipitated shells (contains 54.39 per cent lime), | 100 | 73 |
| 5. Wiesenkalk (contains 32.14 per cent. lime), used in fresh, soft state, | 96 | 100 |
| 6. Caustic lime, powder, prepared from marble, | 98 | 79 |
| 7. Chalk lime (Lüneborg manure), (51 per cent. lime), | 98 | 80 |
| 8. Coral chalk (54.9 per cent. lime in dry substance), | 84 | 84 |
| 9. White Carrara marble, | 88 | 87 |
| 10. Precipitated chalk from sugar factory, | ..... | 86 |

The carbonates were finely powdered and passed through a very fine sieve before application.

In both cases higher results were obtained from certain carbonates than from the caustic limes.

On the other hand, the caustic action of lime as a fungicide or vermicide, can not be performed by the carbonate. Laboratory experiments also indicate a far less vigorous direct chemical action by the carbonate than by the caustic compound in decomposing organic matters.

General experience, especially upon heavy soils, leads to a decided preference for the burnt lime. Loudon* says: "The effect of powdered limestones * * * as a manure * * * is so much inferior to that of burnt lime that they have long since been laid aside."

But this may be due solely to the fact that it is not practicable to secure by purely mechanical means so fine a state of sub-division as that which is attained by burning and slaking.

### LIME IN MASS NOT COMPLETELY CARBONATED.

Reasoning by analogy from the rate at which lime air-slakes in the heap, it is almost necessary to assume that lime can not long remain caustic after it has been spread and worked into the soil in a finely divided state. It is true, though, that compact lumps or masses of calcium hydrate, once their surfaces are carbonated, change very slowly through their interior portions. Thus, Reid states that upon examining mortar used several centuries since in the construction of

*Encyclopedia of Agriculture, § 387.

certain European buildings, the interior portions of the mortar were found to exist, even yet, in an uncarbonated, caustic condition.

### CONDITION OF LIME AND MAGNESIA IN TREATED SOILS.

To secure direct evidence upon the state of combination of the lime and magnesia at the end of the experiments made in our laboratory and to further examine into the allegation that magnesium lime may owe its sometimes injurious action to the slower rate of its carbonatation, a careful determination of the amounts of carbonic acid present in the soils treated with lime and magnesia was made by Mr. C. W. Norris, using the method previously used upon the original soils. The results were as follows:

TABLE XV—Percentage of Carbonic Acid in Treated Soils.

| Soils. | Lime treatment. | Magnesia treatment. |
|---|---|---|
| I, | 0.207 | 0.094 |
| II, | 0.163 | 0.046 |
| III, | 0.235 | 0.095 |
| IV, | 0.116 | 0.269 |
| V, | 0.110 | 0.020 |
| VI, | 0.039 | 0.030 |
| VII, | 0.202 | 0.068 |
| VIII, | 0.135 | 0.015 |
| IX, | 0.133 | 0.045 |

Using these percentages and those obtained for the original soils, and correcting for the differences in soil moisture, but neglecting, as inconsiderable, any changes in weight the soils might have undergone from other causes, the percentages of the added lime and magnesia that had become converted to carbonates by the end of the experiment are estimated to be as follows:

TABLE XVI—Percentage of Alkaline Earths Carbonated in the Soil.

| Soils. | Lime Treatment. | Magnesia Treatment. |
|---|---|---|
| I, | 43.8 | 15.1 |
| II, | 31.7 | 1.8 |
| III, | 50.9 | 15.3 |
| IV, | 18.2 | 56.9 |
| V, | 21.7 | * |
| VI, | * | * |
| VII, | 41.5 | 7.5 |
| VIII, | 26.6 | * |
| IX, | 21.5 | * |

In those cases marked with a star, less carbonic acid was found at the end than at the beginning of the experiment. After ten months in thorough admixture with soils more or less supplied with humus, less than half the lime had combined with carbonic acid, in all but one soil. In the muck soil there was no more carbonic acid than at the outstart.

Concerning the conditions of these experiments it may be remarked that the lime did not lie exposed upon the surface of the soil for any length of time, nor was the contact of the soil with carbonic acid from the air so complete as would be the case in an open field. On the other hand, however, the lime was very finely sub-divided and well distributed through soils in which there was considerable decay of humus during the progress of the experiment, such as is supposed to furnish carbonic acid in abundance.

The evidence favors the belief that the conversion of caustic lime to carbonate in the soil may be much less rapid than has been heretofore assumed. The evidence does not, however, show positively the state of combination in which the uncarbonated lime exists. Some of it is doubtless affiliated with the silicates, humates or ulmates, nitrates and phosphates of the soil, but considering the relatively large quantity applied, it is difficult to conceive that a very large fraction has not remained in caustic condition.

### MAGNESIA LESS READILY CARBONATED.

As for the magnesia, it evidently carbonates much less readily than the lime, and the inference that the evil effects sometimes observed after its application in magnesian limes, may be due to its persistent causticity, is strongly supported.

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## SUMMARY OF RESULTS OF THE PENNSYLVANIA EXPERIMENTS.

1. Most of the soils contained a moderate amount of lime, only two being strikingly deficient.

2. All but one contained more magnesia than lime.

3. No effect upon the moisture relations followed the use of lime. Very probably the failure to discover such effect is due to a faulty preparation of the soil for observation.

4. Liming was, in all cases, followed by increased availability of the potash, sometimes to nearly 50 per cent. of the original amount available.

5. A similar increase in available phosphoric acid occurred in all but one soil.

6. In four of the soils acidity was evident, so that some of the

benefit derived in practice from liming these soils is attributable to the neutralization of the acid.

7. There was less loss of total organic matter, but more loss of active humus as the result of liming compared with fallowing.

8. Liming resulted in a diminution of the nitrogen, from loss of ammonia in all probability; a marked increase in nitrates and, in one soil, of nitrogen in other organic compounds than the amids. The nitrogen in the form of amids, in one soil, and of active humus suffered a decided decrease.

9. At the end of ten months, much less than 50 per cent., on the average, of the added lime had turned to carbonate.

10. As for the magnesia, it liberated potash as freely as did lime, on the average; was even more influential than lime in its average effect in rendering the phosphoric acid more assimilable; an even smaller quantity would suffice of magnesia than of lime as a corrective of acidity; it affected total organic matter and *matiere noire* in manner and degree like lime, as also it did the various nitrogenous compounds, except that ammonia was more abundant in its presence. It carbonated very much less readily than lime.

So that, in general, its functions in the soil are very similar to those of lime. It is only when it is applied in large quantity so that it may keep the soil too highly alkaline for a long period or may, in some other manner, act poisonously upon the plant in the absence of a proper proportion of lime, that ground is given for objection to its use. Moderate applications of most of the magnesian limes of Pennsylvania can be made without fear when liming is indicated as desirable.

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## SOME FINAL PRACTICAL CONSIDERATIONS.

### CIRCUMSTANCES SUGGESTING THE USE OF LIME.

It is not possible to indicate certainly all cases in which liming is admissible. Its use is clearly suggested as needful, sooner or later, upon light uplands whose characteristic vegetation shows that lime is not abundant. When soils are acid, whether from the oxidation of sulfids, from the residues of fertilizers or from humus; when clay soils become too adhesive; when swamp lands are to be brought rapidly into bearing (in both these last named cases, draining must precede liming to secure the full efficiency of the latter). It will be

helpful when heavy sod, a large green-manuring crop or a heavy dressing of very strawy manure is to be turned under, especially in a soil deficient in lime or magnesia; in these cases a good distribution of the lime in contact with the decaying vegetable matter should, in one way or another, be secured. When clover persistently fails, a moderate liming is suggested as a possible necessity before securing a good growth. It is clearly indicated on lands where turnips suffer from the "finger-and-toe" disease, but should be avoided where potatoes are to follow soon in the rotation. Where lime is cheap, it may prove, for a time, the cheapest means of securing available potash, by its action upon the unavailable supply already present in the soil. On soils relatively rich in iron and requiring the use of phosphatic fertilizers, a moderate dressing of lime before the time of fertilizing will greatly increase the duration of effect of the phosphate.

On the other hand, liming alone is insufficient on poor lands; they may respond well for a brief time, but are soon exhausted of the materials upon which lime can react. On such lands, heavy manuring must go hand in hand with liming. Indeed, even on lands of good heart, care must be taken to maintain the humus supply when liming is constantly practised.

### FREQUENCY OF LIMING.

As to the frequency of liming, circumstances must somewhat determine. A single heavy dressing of lime may correct the undue plasticity of a clay and retain it in a flocculated condition for many years, particularly when it is tilled with judgment; later, light dressings applied at not too great interval, will suffice to retain the desirable texture indefinitely. For the correction of acidity a single heavy dressing may suffice for years. Where, however, the immediate breaking down of vegetable matter is desired, an application, at the time, of a properly adjusted quantity of lime would seem advisable.

### QUANTITY TO BE APPLIED.

As to the quantity of lime applied: this must depend upon the frequency of the application, as well as upon the purpose sought to be accomplished. In correcting the plasticity of a heavy clay, or the acidity of a soil, or in preparing new land, rich in humus, for some intensive culture such as onion growing or celery, the first dressing may need to be heavy. An application of upwards of 100 bushels of slaked lime would doubtless prove economical in a few such cases. Good results have attended the use, in such circumstances, of as much as 500 bushels of slaked lime; but it is rare that better growth is observed where the lime was thickly spread, near the heap or wagon,

than where it lies more thinly upon the ground at the points more remote from the center of distribution. In general, it would be wise to prove by actual test that more than 100 bushels actually gives a paying result over and above that yielded by the smaller dressing, before going to the expense of the heavier application. As lime does not retain its maximum efficiency for a very long time, as it is among the substances more easily removed from the soil by drainage and, particularly, as it tends to pass quickly into the sub-soil while its effects are chiefly sought in the surface soil, lighter dressings at more frequent intervals are more likely to produce an economical result than very heavy dressings at longer intervals. Indeed, it may safely be stated as a rule applicable to most cases, that when the soil has already been brought into fair condition, an application of fifty bushels or even less will suffice to maintain heavy lands in good tilth and fertility if made once in six to ten years. On lighter soils, under like conditions otherwise, the dressing may often show its maximum benefit if no greater than twenty-five bushels. For light lands especially, is the maxim of very light dressings made more frequently, to be adopted. The dressing should be larger, the deeper the surface soil.

### WHEN TO LIME.

For special purposes, the time for liming indicates itself—as in correcting some injurious condition of the soil, such as adhesiveness or acidity, or as in the preparation of new land for use, or as in the top dressing of a permanent meadow when clovers are failing.

But some plants, as Wheeler* has remarked, are especially liable to injury from the effect of caustic lime, and its use just before their planting is not commendable unless circumstances compel it; such crops are Indian corn, rye and millet. On the other hand, certain crops, such as beets, lettuce, spinach, celery, cauliflower, kohl rabi, onions, muskmelon, cantaloupes, salsify, cabbages, cucumbers, etc., seem to thrive especially well immediately after a liming. For the general purpose of maintaining in the soil an adequate supply of calcium carbonate, with all its attendant advantages and, at the same time, of gaining the maximum immediate advantage upon that crop in our general rotations that most fully responds to lime, it is believed that the use of a small quantity when seeding down or, in some ways even better, as a top dressing upon the clover in wheat or oats stubble, will give the largest return.

### PREPARATION OF LIME.

The precautions that should be taken to keep the lime in a caustic state and to secure its proper slaking have already been stated with

*Bulletin 46, R. I. Agr. Exp. Sta., p. 94.

the reasons therefor. It only needs to be added that the lime should be worked thoroughly into the surface soil as soon as it is spread, except when it is to be plowed under with sod, green or stable manure, or when, of course, it is added as a top dressing to a growing crop.

### METHOD OF APPLICATION.

When used before corn, it is commonly better to apply in the fall or winter, if spring plowing is adopted, and the plowing is shallow. In this way, the best return to the crop is often secured. If, however, the plowing is deep, better results have often attended the use of lime as a top dressing harrowed in some days before corn planting. There is some reason for believing that where the sod is very heavy, and is to be deep plowed, a division of the application, part upon the sod, and part, later, as a top dressing, would be more beneficial. The various means of distribution have been earlier discussed.

### LIME SUBSTITUTES.

Where lime is not readily accessible, carbonate of lime is sometimes to be had in the form of leached wood ashes, tannery ashes or marl. The quantity to be applied must vary with the composition. It requires nearly twice as much carbonate as of pure, unslaked quicklime to perform a given work; often much more, from the fact that the ash, marl, etc., are much coarser grained.

Unleached wood ashes require some caution when used in large quantities. The considerable quantities of potassium carbonate they contain, often more than neutralize the flocculating effect of the calcium carbonate and leave a heavy soil even more adhesive and compact than before the application of the ash; but they are more efficient than lime in compacting very light soils.

# APPENDIX A.

## I.—LIST OF FARM CORRESPONDENTS—BY COUNTIES.

| | |
|---|---|
| Adams, | Mr. L. W. Lighty, East Berlin. |
| | Mr. Geo. P. Myers, Flora Dale. |
| Armstrong, | Mr. S. S. Blyholder, Leechburg. |
| | Mr. A. M. Hindman, Craigsville. |
| Beaver, | Mr. Wm. T. Anderson, New Galilee. |
| Bedford, | Hon. J. S. Biddle, Loysburg. |
| | Mr. G. W. Oster, Osterburg. |
| | Mr. Thomas P. Beckley, Alum Bank. |
| Berks, | Hon. George D. Stitzel, Reading. |
| | Mr. J. W. Albright, Shartlesville. |
| Blair, | Mr. Frederick Jaekel, Hollidaysburg. |
| Bradford, | Mr. S. W. Lester, Troy. |
| | Mr. Asa S. Stevens, Franklindale. |
| Bucks, | Mr. John K. Scarborough, Pineville. |
| | Mr. Ezra Michener, Carversville. |
| | Mr. F. L. Mulford, Edgewood. |
| Butler, | Mr. Harlan Book, Euclid. |
| | Mr. O. W. Stoughton, Prospect. |
| Cambria, | Mr. David B. Wertz, Johnstown. |
| | Mr. John E. Tomlinson, Loretto. |
| Cameron, | Mr. E. M. Fairchild, Sizerville. |
| | Mr. B. V. Wykoff, Sinnemahoning. |
| Carbon, | Mr. George T. Wells, Rockport. |
| Centre, | Mr. T. M. Gramley, Spring Mills. |
| | Col. J. F. Weaver, Milesburg. |
| Chester, | Mr. R. M. Simmers, Phoenixville. |
| Clinton, | Mr. Joel A. Herr, Cedar Springs. |
| Columbia, | Mr. A. P. Young, Millville. |
| | Mr. Albert Cope, Berwick. |
| | Hon. William T. Creasy, Catawissa. |
| Crawford, | Mr. John C. McClintock, Meadville. |
| Cumberland, | Hon. S. M. Wherry, Shippensburg. |
| | Mr. B. D. Biggs, Shippensburg. |
| Dauphin, | Mr. S. F. Barber, Harrisburg. |
| | Mr. John Moyer, Gratz. |
| | Mr. Gabriel Hiester, Harrisburg. |

Delaware, ..... Mr. Joseph H. Paschall, Ward.
Mr. William M. Ott, Station M, Philadelphia.
Elk, ..... Mr. J. M. Wittman, St. Marys.
Mr. Joseph Kaiser, St. Marys.
Erie, ..... Mr. H. H. Russell, Belle Valley.
Hon. H. H. Chaffee, Lowville.
Mr. B. J. Crowell, Lovell's Station.
Fayette, ..... Mr. W. E. Crawford, Belle Vernon.
Forest, ..... Mr. C. A. Randall, Tionesta.
Mr. T. D. Collins, Nebraska.
Franklin, ..... Mr. Henry Omwake, Greencastle.
Mr. C. B. Hege, Marion.
Dr. A. H. Strickler, Waynesboro.
Fulton, ..... Mr. J. F. Johnston, Webster Mills.
Hon. S. P. Wishart, Wells' Tannery.
Greene, ..... Mr. N. H. Biddle, Carmichaels.
Huntingdon, ..... Mr. George G. Hutchison, Warrior's Mark.
Mr. T. O. Milliken, Cornpropst's Mills.
Dr. W. T. Browning, Orbisonia.
Indiana, ..... Hon. N. Seanor, Denton.
Hon. John Hill, Blairsville.
Jefferson, ..... Mr. James McCracken, Frostburg.
Mr. John H. Lewis, Frostburg.
Juniata, ..... Mr. J. T. Ailman, Thompsontown.
Mr. D. B. McWilliams, Walnut.
Lackawanna, ..... Mr. J. H. Hathrill, Moscow.
Lancaster, ..... Capt. J. P. Bricker, Lititz.
Mr. James Collins, Quarryville.
Lawrence, ..... Mr. George Dean, Princeton.
Mr. Thomas Love, Hillsville.
Lebanon, ..... Mr. Samuel Groh, Lickdale.
Lehigh, ..... Mr. Alfred J. S. Diefenderfer, South White Hall.
Mr. P. P. Mohr, Fogelsville.
Luzerne, ..... Mr. John R. Gould, Bell Bend.
Mr. William J. Honeywell, Dallas.
Mr. H. B. Larned, Huntingdon Mills.
Lycoming, ..... Mr. Abner Fague, Picture Rocks.
Mr. R. H. Grier, Jersey Shore.
Hon. A. J. Kahler, Hughesville.
McKean, ..... Mr. Eugene Mullin, Bradford.
Dr. A. B. Armstrong, Smethport.
Mr. T. M. McClellan, Mt. Jewett.
Mercer, ..... Mr. J. C. Mossford, Millbrook.
Mifflin, ..... Mr. R. A. Naginey, Milroy.

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|---|---|
| Monroe, | Mr. Emil Ulrich, Stroudsburg. |
| | Mr. Randall Bisbing, Minsi. |
| | Hon. R. F. Schwarz, Analomink. |
| Montgomery, | Hon. Jason Sexton, Spring House. |
| Northampton, | Hon. B. B. McClure, Bath. |
| | Mr. W. M. Benniger, Walnutport. |
| | Mr. Albin F. Meyer, Moorestown. |
| Northumberland, | Mr. C. N. Marsh, Pottsgrove. |
| | Mr. B. F. Reitz, Elysburg. |
| Perry, | Mr. C. L. Steele, Duncannon. |
| | Mr. George S. Barnett, New Bloomfield. |
| | Mr. James E. Stephens, Acker. |
| Philadelphia, | Mr. J. B. Kirkbride, Bustleton. |
| Pike, | Mr. J. H. VanEtten, Milford. |
| Potter, | Mr. W. A. Gardner, Andrews' Settlement. |
| | Mr. John McDowell, Pleasant Valley. |
| Schuylkill, | Mr. W. H. Stout, Pine Grove. |
| | Mr. W. H. Riland, Friedensburg. |
| Snyder, | Mr. M. K. Hassinger, Middleburg. |
| | Mr. Jacob H. Hetrick, Beavertown. |
| Somerset, | Hon. N. B. Critchfield, Critchfield. |
| | Mr. C. S. Beal, Elklick. |
| Susquehanna, | Mr. E. W. Watson, New Milford. |
| Tioga, | Mr. F. E. Field, Balsam. |
| | Mr. Homer Wilson, Mansfield. |
| | Mr. W. W. Inscho, Canoe Camp. |
| | Mr. William Norman, Sebring. |
| Union, | Mr. R. J. Moyer, White Deer. |
| | Mr. H. G. McCarty, Spring Garden. |
| | Mr. John A. Gundy, Lewisburg. |
| Venango, | Mr. Porter Phipps, Kennerdell. |
| Warren, | Mr. R. J. Weld, Sugar Grove. |
| | Mr. J. P. Samuelson, Chandler's Valley. |
| Washington, | Mr. J. G. Berry, Primrose. |
| | Mr. J. B. Painter, Independence. |
| Wayne, | Mr. W. E. Perham, Niagara. |
| Westmoreland, | Mr. Geo. S. Barnhart, Greensburg. |
| | Mr. Daniel H. Pershing, Stauffer. |
| | Mr. John W. Welch, Bradenville. |
| Wyoming, | Mr. E. H. Pinder, Centremoreland. |
| | Mr. C. E. Henning, North Mehoopany. |
| York, | Mr. George F. Saubel, Brodbecks. |
| | Hon. James A. Stahle, Emigsville. |

## II.—ADDRESSES OF LIME BURNERS AND DEALERS GIVING INFORMATION.

| | |
|---|---|
| Berks, | Mr. M. G. Oberholtzer, Bechtelsville. |
| | J. S. Pearson & Co., Calcium. |
| | Dr. D. Heber Plank, Morgantown. |
| | Mr. Jacob Shaffner, Host. |
| Blair, | Keystone Lime and Stone Company, Tyrone. |
| | Mr. John Manning, Hollidaysburg. |
| | Mr. J. King McLanahan, Jr., Hollidaysburg. |
| Chester, | Avondale Lime and Stone Co., Avondale. |
| | Mr. Isaac Lesher, Williamson. |
| Jefferson, | Mr. Joseph M. Swisher, Punxsutawney. |
| Lancaster, | Mr. I. Galen Lefevre, Quarryville. |
| Lebanon, | Mr. John A. Bachman, Annville. |
| Lehigh, | Mr. A. W. Held, Fogelsville. |
| | Mr. E. D. Boyer, Catasauqua. |
| Lycoming, | Mr. Abraham Meyer, Cogan House. |
| | Mr. J. Sebring, Jersey Shore. |
| Monroe, | Mr. John P. Carmer, Bossardsville. |
| | Mr. Peter M. Heller, Bossardsville. |
| | Mr. Allen Metzger, Stormville. |
| Montgomery, | Mr. G. W. H. Corson, Plymouth Meeting. |
| | Todd & Son, Port Kennedy. |
| Northampton, | Mr. Edward Fehnel, Nazareth. |
| Northumberland, | Mr. A. C. Baylor, Milton. |
| Tioga, | Mr. D. F. Gates, Mansfield. |
| York, | Bittinger & Eberly, Hanover. |
| Sussex, N. J., | Mr. George N. Cole, Montague. |

# APPENDIX B.

# ANALYSES OF PENNSYLVANIA LIMESTONES.

COMPILED BY

WILLIAM FREAR AND C. A. BROWNE, JR.,

FROM THE

REPORT OF THE SECOND GEOLOGICAL SURVEY OF PENNSYLVANIA; THE CATALOGUE OF EXHIBITS OF THE DEPARTMENT OF MINES, WORLD'S FAIR COMMISSION OF THE STATE OF PENNSYLVANIA; AND THE RECORDS OF THE PENNSYLVANIA STATE COLLEGE AGRICULTURAL EXPERIMENT STATION.

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SYMBOLS USED.

$Al_2 O_3$.—Alumina.
Ca $Co_3$.—Carbonate of lime.
Fe.—Iron.
Fe O.—Iron oxid.
$Fe_2 O_3$.—Iron peroxid.
$Fe_2 CO_3$.—Carbonate of iron.
Fe $S_2$.—Iron pyrites.
$H_2 O$.—Water.
Mg $CO_3$.—Carbonate of magnesia.
$Mn_2 O_3$.—Manganese oxid.
Ca $SO_4$.—Calcium sulfate.
Si $O_2$.—Silica.
$SO_3$.—Sulfuric acid.
$P_2 O_5$.—Phosphoric acid.
Mn $CO_3$.—Carbonate of manganese.
$K_2O$.—Potash.

| Compilation number. | County. | Town. | Owner. | Geological Formation. | Remarks. |
|---|---|---|---|---|---|
| 1. | Armstrong, | Putneyville, | Hamilton, | Freeport Upper limestone, | Dark gray, tough. |
| 2. | Armstrong, | Logansport, | Mehaffey & McGill, | Freeport Upper limestone, | Pearl gray, brittle. |
| 3. | Armstrong, | Logansport, | Mehaffey & McGill, | Freeport Upper limestone, | Pearl gray, tough. |
| 4. | Armstrong, | Logansport, | Mehaffey & McGill, | Freeport Upper limestone, | Light pearl gray, hard. |
| 5. | Armstrong, | Rural Village, | J. Riefer, | Freeport Upper limestone, | Dark gray, tough calcite. |
| 6. | Armstrong, | Dayton, | Marshall, | Freeport Upper limestone, | Dark gray, tough calcite. |
| 7. | Armstrong, | Slate Lick, | Monroe, | Freeport Upper limestone, | Dark gray, tough. |
| 8. | Armstrong, | Manorville, | Dull & Co., | Freeport Upper limestone, | Dark gray, compact. |
| 9. | Armstrong, | Manorville, | Dull & Co., | Freeport Upper limestone, | Dark gray, contains pyrite. |
| 10. | Armstrong, | Manorville, | Dull & Co., | Freeport Upper limestone, | Pearl gray, calcite. |
| 11. | Armstrong, | Cochran's Mills, | Davis, | Johnstown cement, | Bluish gray, tough. |
| 12. | Armstrong, | Putneyville, | Putney, | Johnstown cement, | Bluish gray, hard, tough. |
| 13. | Armstrong, | Madison township, | Stewardson Furnace, | Ferriferous limestone, | Pearl gray, contains fossil casts. |
| 14. | Armstrong, | Madison township, | Stewardson Furnace, | Ferriferous limestone, | Pearl gray, contains fossil casts. |
| 15. | Armstrong, | Mahoning Furnace, | Colwell, | Ferriferous limestone, | Bluish gray, contains fossil casts. |
| 16. | Armstrong, | Kittanning, | Reynolds, | Ferriferous limestone, | Pearl gray, fossilferous, calcite. |
| 17. | Armstrong, | South Bend, | George, | Ferriferous limestone, | Dark gray, fossilferous, calcite. |
| 18. | Armstrong, | Greendale, | Rhea, | Ferriferous limestone, | Bluish gray fossilferous, brittle. |
| 19. | Armstrong, | Buffalo Mills, | Graff, | Ferriferous limestone, | Dark gray, brittle. |
| 20. | Armstrong, | Kittanning, | Pine Creek Furnace, | Ferriferous limestone, | Bluish gray, compact. |
| 21. | Blair, | Altoona, | Baker, | Lewistown limestone, Lower Helderburg Form. No. VI, | Light bluish gray, fossilferous upper layer. |
| 22. | Blair, | Altoona, | Baker, | Lewistown limestone, Lower Helderburg Form. No. VI, | Dark gray middle layer, contains calcite. |
| 23. | Blair, | Altoona, | Baker, | Lewistown limestone, Lower Helderburg Form. No. VI, | Gray lower layer, contains calcite. |
| 24. | Blair, | Hollidaysburg, | Creswell, | Lewistown limestone, Lower Helderburg Form. No. VI, | Dark gray, hard, contains calcite. |
| 25. | Blair, | Hollidaysburg, | Manning & Lewis, | Lewistown limestone, Lower Helderburg Form. No. VI, | Pearl gray, compact, contains calcite |

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| 26. | Blair, | Hollidaysburg, | Loop, | Lewistown limestone, Lower Helderburg Form. No. VI, | Dark gray, hard, contains calcite |
| 27. | Blair, | Tyrone, | Keystone Lime and Stone Co., | | Average supplied to Cambria Iron Co. |
| 28. | Blair, | Martinsburg, | John Manning. | | |
| 29. | Blair, | Frankstown, | J. K. McLanahan, | Limestone formation, No. VI., | |
| 30. | Blair, | Frankstown, | J. K. McLanahan, | Limestone formation, No. VI., | |
| 31. | Blair, | Catharine township, | Mt. Etna Furnace, | Limestone Form. No. II, | Bluish gray, contains calcite. |
| 32. | Blair, | | Springfield Furnace, | Limestone Form. No. II, | Dark blue, contains calcite. |
| 33. | Blair, | | Rodman Furnace, | Limestone Form. No. II, | Bluish gray, contains calcite. |
| 34. | Blair. | | Rodman Furnace, | Limestone Form. No. II, | Bluish gray, contained calcite. |
| 35. | Blair, | Roaring Springs, | Rodman Furnace, | Limestone Form. No. II, | Pearl gray. |
| 36. | Blair, | Tyrone, | | Limestone Form. No. II, | Light bluish gray, hard. |
| 37. | Blair, | Tyrone, | | Limestone Form. No. II, | Dark gray, hard. |
| 38. | Blair, | Birmingham, | Borie, | Limestone Form. No. II, | Bluish gray, hard, compact. |
| 39. | Blair, | Birmingham, | Keystone Zinc Co., | Limestone Form. No. II, | Bluish gray, conglomerate-like. |
| 40. | Bradford, | Burlington, | W. B. Kline. | Limestone Form. No. VIII, | "Burlington limestone," small fossil shells. |
| 41. | Berks, | Morgantown, | D. H. Plank, | Next to gneiss or primitive. | |
| 42. | Berks, | Bechtelsville, | M. G. Oberholtzer, | | |
| 43. | Berks, | Robesonia, | S. R. Deppan, | | For lime. |
| 44. | Berks, | Caernarvon, | P. De Plank, D. Heber Plank. | | |
| 45. | Berks, | Caernarvon, | P. De Plank, D. Heber Plank. | | |
| 46. | Berks, | Caernarvon, | P. De Plank, D. Heber Plank. | | |
| 47. | Berks, | Caernarvon, | P. De Plank, D. Heber Plank. | | |
| 48. | Beaver, | Vanport township, | Severn, | Ferriferous limestone, | Reddish gray, brittle. |
| 49. | Beaver, | Vanport township, | Power, | Ferriferous limestone, | Reddish gray, brittle. |
| 50. | Beaver, | Vanport township, | Power, | Ferriferous limestone, | Reddish gray, brittle, contains calcite and pyrite. |
| 51. | Beaver, | Vanport township, | Tygart, | Ferriferous limestone, | Reddish gray, brittle. |
| 52. | Cumberland, | Pine Grove, | Pine Grove Furnace, | Siluro-Cambrian No. II, | Brownish gray, hard. |
| 53. | Cumberland, | Mt. Holly, | Craig Head, | Siluro-Cambrian No. II, | Dark bluish gray, hard. |
| 54. | Cumberland, | Harrisburg, | | Siluro-Cambrian, | Dark bluish gray, soft, top of bed CXV. |
| 55. | Cumberland, | Harrisburg, | | Siluro-Cambrian, | Dark bluish gray, soft, bottom of bed CXV. |
| 56. | Cumberland, | Harrisburg, | | Siluro-Cambrian, | Dark gray, soft, compact, top of bed LXXXVI. |
| 57. | Cumberland, | Harrisburg, | | Siluro-Cambrian, | Dark gray, soft, compact, bottom of bed LXXXVI. |
| 58. | Cumberland, | Harrisburg, | | Siluro-Cambrian, | Dark gray, hard, compact, calcite, top of bed LXXXVII. |
| 59. | Cumberland, | Harrisburg, | | Siluro-Cambrian, | Dark gray, hard, compact, calcite, bottom of bed LXXXVII. |
| 60. | Cumberland, | Harrisburg, | | Siluro-Cambrian, | Light gray, hard, compact, calcite, top of bed XCVIII. |
| 61. | Cumberland, | Harrisburg, | | Siluro-Cambrian, | Light gray, hard, compact, bottom of bed XCVIII. |
| 62. | Centre, | Oak Hall, | P. Dale, Dale. | | |
| 63. | Centre, | Oak Hall, | P. Dale, Dale. | | |
| 64. | Centre, | Oak Hall, | P. Dale, Dale. | | |
| 65. | Centre, | Oak Hall, | P. Dale, Dale. | | |
| 66. | Centre, | Boalsburg, | W. C. Myer. | | |

| Compilation number. | County. | Town. | Owner. | Geological Formation. | Remarks. |
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| 67. | Centre, | Boalsburg, | W. C. Myer. | | |
| 68. | Centre, | Bellefonte, | F. S. Rhoads, | | Surface inch. |
| 69. | Centre, | Snoe Shoe Basin, | | | Dirty gray, siliceous. |
| 70. | Centre, | Snoe Shoe Basin, | | | Very silicious. |
| 71. | Centre, | Bellefonte, | Shortlidge, | Siluro-Cambrian Form. No. II, | Hard compact, contains calcite, pearl gray. |
| 72. | Centre, | Bellefonte, | Shortlidge, | Siluro-Cambrian Form. No. II, | Hard compact, contains calcite, pearl gray. |
| 73. | Centre, | Bellefonte, | Shortlidge, | Siluro-Cambrian Form. No. II, | Hard compact, contains calcite, pearl gray. |
| 74. | Chester, | Avondale, | Avondale Lime and Stone Co., | | |
| 75. | Chester, | Barker Station, | Acme Lime Co., | | For building. |
| 76. | Chester, | Barker Station, | Acme Lime Co., | | For building and fluxing. |
| 77. | Chester, | Avondale, | Avondale Marble Co., | | Statuary marble. |
| 78. | Chester, | London Grove Twp., | Swayne, | Siluro-Cambrian Form. No. II, | Brownish grey, crumbling. |
| 79. | Clarion, | New Athens, Madison Twp., | | Freeport Upper limestone, | Dark gray, calcite. |
| 80. | Clarion, | Perry township, | Reichert, | Freeport Upper limestone, | Dark gray, calcite. |
| 81. | Clarion, | Toby township, | | Freeport Upper limestone, | Bluish gray, hard. |
| 82. | Clarion, | Porter township, | | Ferriferous limestone, | Pearl gray, brittle. |
| 83. | Clarion, | Clarion township, | Hindman, | Ferriferous limestone, | Bluish gray, brittle, calcite. |
| 84. | Clarion, | Piney township, | Sligo Furnace, | Ferriferous limestone, | Bluish gray, tough. |
| 85. | Clarion, | Perry township, | Barger, | Ferriferous limestone, | Bluish gray, calcite. |
| 86. | Cambria, | Johnstown, | A. J. Hawes, | Cement bed, | Hard, brittle, contains pyrites. |
| 87. | Clearfield, | Glenn Hope, | | | Bluish gray, hard. |
| 88. | Clinton, | Nippenose Valley, | J. Wilsham, | Siluro-Cambrian No. II, | So-called "plaster." |
| 89. | Crawford, | Harmonsburg, Summit township, | Whiting & Brown, | | A raw marl, covers 80 acres; used for lime and agriculture. |
| 90. | Dauphin, | Harrisburg, | Rutherford, | Limestone Form No. II, | Dark bluish gray, East quarry. |
| 91. | Dauphin, | Harrisburg, | Rutherford, | Limestone Form No. II, | Dark bluish gray, West quarry. |
| 92. | Dauphin, | Harrisburg, | Couffer, | Limestone Form No. II. | |
| 93. | Dauphin, | Harrisburg, | Frantz, | Limestone Form No. II. | |
| 94. | Dauphin, | Harrisburg, | Crumbler, | Limestone Form No. II. | |
| 95. | Dauphin, | Harrisburg, | Strickler, | Limestone Form No. II. | |
| 96. | Elk, | Brandy Camp, Horton twp., | J. S. Hyde, | Freeport Upper limestone, | Bluish gray, brittle. |

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| 97. | Elk, | Brandy Camp, Horton twp., | J. S. Chamberlain, | Freeport Lower limestone, | Bluish gray, brittle. |
| 98. | Elk, | Brandy Camp, Horton twp., | J. C. McAllister, | Freeport Lower limestone, | Pearl gray, brittle. |
| 99. | Elk, | Mead Run, Horton twp., | T. Fox, | Freeport Lower limestone, | Bluish gray, brittle. |
| 100. | Elk, | Benezette, | G. W. Winslow, | Ferriferous limestone, | Pearl gray, brittle, calcite. |
| 101. | Elk, | Fox township, | J. S. Chamberlain, | Ferriferous limestone, | Bluish gray, brittle. |
| 102. | Elk, | Brandy Camp, | J. C. McAllister, | Ferriferous limestone, | Bluish gray, brittle. |
| 103. | Elk, | Brandy Camp, | J. C. McAllister, | Johnstown cement bed, | Bluish gray, hard and tough. |
| 104. | Elk, | Brockport, | Oyster, | Ferriferous limestone, | Bluish black, shaly, fossiliferous, soft. |
| 105. | Elk, | Brockport, | Oyster, | Ferriferous limestone, | Dark blue, brittle. |
| 106. | Elk, | Brockport, | Oyster, | Ferriferous limestone, | Bluish black, shaly, fossiliferous. |
| 107. | Elk, | Jones township, | Gen. Kane, | Ferriferous limestone, | Reddish gray, brittle. |
| 108. | Elk, | Jones township, | Gen. Kane, | Ferriferous limestone, | Bluish gray, brittle, calcite. |
| 109. | Elk, | Fox township, | | Clermont limestone, | Bluish gray, brittle. |
| 110. | Elk, | Benezette, | | Benezette Upper limestone, | Bluish gray, sandy fossiliferous. |
| 111. | Elk, | Benezette, | | Benezette Middle limestone, | Bluish gray, shaly, fossiliferous. |
| 112. | Elk, | Caledonia, | | | Bluish gray, crystalline, has pyrites. |
| 113. | Elk, | Caledonia, | | | Bluish gray, very sandy. |
| 114. | Elk, | St. Mary's, | J. M. Wittman. | | |
| 115. | Fayette, | Georges township, | Oliphant Furnace, Oliphant, | Sewickley limestone, | Blue, compact and contains pyrites. |
| 116. | Fayette, | Uniontown, | Lemont Furnace, | Redstone limestone, | Compact, brittle, contains calcite. |
| 117. | Fayette, | Uniontown, | Lemont Furnace, | Pittsburgh limestone, | Bluish gray, soft, brittle. |
| 118. | Forest, | Tionesta, | Kelly, | Tionesta limestone, | Bluish gray, hard, tough, sandy. |
| 119. | Franklin, | Mont Alto, | Mine No. 3 Iron Co., | | Yellowish brown, soft. |
| 120. | Franklin, | Mont Alto, | Mine No. 4 Iron Co., | | Light bluish gray, soft. |
| 121. | Franklin, | Mont Alto, | Shiery, | | A true lithological dolomite. |
| 122. | Franklin, | Williamson, | Hawbecker, | | Best quality from quarry. |
| 123. | Franklin, | Williamson, | Hawbecker, | | Worst quality from quarry. |
| 124. | Franklin, | Scotland, | Battin, | Siluro-Cambrian No. II, | A cement quarry, now abandoned. |
| 125. | Huntingdon, .....4..... | Union Furnace Station, | H. J. McAteer, | | For fluxing and R. R. ballast. |
| 126. | Huntingdon, | Three Springs, | Hudson, | Lewistown limestone, Lower Helderberg Form. No. VI, | Compact, bluish gray, 70 feet above bottom of formation. |
| 127. | Huntingdon, | Three Springs, | Hudson, | Lewistown limestone, Lower Helderberg Form. No. VI, | Compact bluish gray, 60 feet above bottom of formation. |
| 128. | Huntingdon, | Three Springs, | Hudson, | Lewistown limestone, Lower Helderberg Form. No. VI, | Compact bluish gray, 50 feet above bottom of formation. |
| 129. | Huntingdon, | Saltillo, | C. R. McCarthy, | Lewistown limestone, Lower Helderberg Form. No. VI, | Crystalline bluish gray, contains calcite. |
| 130. | Huntingdon, | Saltillo, | C. R. McCarthy, | Lewistown limestone, Lower Helderberg Form. No. VI, | Siliceous, bluish gray. |
| 131. | Huntingdon, | Saltillo, | | Lewistown limestone, Lower Helderberg Form. No. VI, | Water line cement beds, 375 feet above bottom of formation. |

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| 132. | Huntingdon, | Saltillo, | | Lewistown limestone, Lower Helderberg Form. No. VI, | Water line cement beds, 190 feet above bottom of formation. |
| 133. | Huntingdon, | Saltillo, | | Lewistown limestone, Lower Helderberg Form. No. VI, | Water line cement beds, 160 feet above bottom of formation. |
| 134. | Huntingdon, | McAlevy's Fort, | Barr, | 80+ ft. below fossil ore. | Bluish gray, dark, compact, contains calcite. |
| 135. | Huntingdon, | Robertsdale. | | | Conglomerate of limestone and red shale. |
| 136. | Huntingdon, | Broad Top City, | J. Diggins, | | Conglomerate of limestone and red shale. |
| 137. | Huntingdon, | Todd township, | John Whitney, | Red Shale No. XI, Mauch Chunk, | Bluish gray, tough. |
| 138. | Indiana, | West Lebanon, | A. H. Fulton, | Pittsburgh limestone, | Bluish gray, compact, brittle. |
| 139. | Indiana, | Five Points, | Rev. S. Brown, | Freeport Upper limestone, | Bluish gray, compact, calcite. |
| 140. | Indiana, | Chambersville, | Groft Brothers, | Freeport Upper limestone, | Dark bluish gray, compact. |
| 141. | Indiana, | Jacksonville, | S. C. Hazlelett, | Freeport Upper limestone, | Bluish gray, compact. |
| 142. | Indiana, | Homer, | D. R. Griffith, | Freeport Upper limestone, | Bluish gray, compact. |
| 143. | Indiana, | Blairsville, | G. Livengood. | Freeport Upper limestone, | Bluish gray, compact. calcite. |
| 144. | Indiana, | Richmond, | Isaac Simpson, | Ferriferous limestone, | Bluish gray, hard, fossilliferous. |
| 145. | Indiana, | Blairsville, | Doty, | 120 ft. below Pittsburgh coal bed, | Bluish gray, compact, contains calcite. |
| 146. | Indiana, | Decher's Point, | S. Palmer, | Freeport Lower limestone, | Bluish gray, brittle. |
| 147. | Indiana, | Blairsville, | P. Brown, | Freeport Lower limestone, | Bluish gray, brittle. |
| 148. | Indiana, | Smithport, | A. Gorman, | Johnstown cement bed, | Upper part of deposit, hard. |
| 149. | Indiana, | Smithport, | A. Gorman, | Johnstown cement bed, | Lower part of deposit, hard. |
| 150. | Indiana, | Black Lick Station, | Tyhawk, | Johnstown cement bed, | Bluish gray, compact. |
| 151. | Indiana, | Smith's Station, Blairsville, | Robert Smith. | Sewickly limestone, | Compact, contains calcite. |
| 152. | Indiana, | Marion Center, | J. H. Rochester, | | Compact gray, red tinge, coarse top seam. |
| 153. | Indiana, | Marion Center, | J. H. Rochester, | | Red, middle seam. |
| 154. | Indiana, | Marion Center, | J. H. Rochester, | | Red, bottom seam. |
| 155. | Indiana, | Home, | T. St. Clair Thompson, | | Surface rock. |
| 156. | Indiana, | Home, | T. St. Clair Thompson. | | |
| 157. | Indiana, | Home, | T. St. Clair Thompson. | | |

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| 158. | Juniata, | Mexico, | Mr. Rodgers. | | |
| 159. | Jefferson, | Big Run, | Jas. Smith, | Lower Barren Measures, | Bluish gray, brittle. |
| 160. | Jefferson, | Big Run, | James Smith, | Lower Barren Measures, | Pearl gray, hard and tough. |
| 161. | Jefferson, | Big Run, | Jacob Smith, | Lower Barren Measures, | Bluish gray, brittle, calcite. |
| 162. | Jefferson, | Brockwayville, | N. B. Lane, | Freeport Upper limestone, | Pearl gray, brittle, calcite. |
| 163. | Jefferson, | Perrysville, | John Iler, | Freeport Upper limestone, | Pearl gray, sandy. |
| 164. | Jefferson, | Perrysville, | John Iler, | Freeport Upper limestone, | Bluish gray, brittle, calcite. |
| 165. | Jefferson, | Frostburg, | D. Hopkins, | Freeport Upper limestone, | Pearl gray, brittle, calcite. |
| 166. | Jefferson, | Worthville, | A. Hoffman, | Freeport Upper limestone, | Pearl gray, brittle, calcite. |
| 167. | Jefferson, | Brockwayville, | N. B. Lane, | Freeport Lower limestone, | Brownish gray, brittle. |
| 168. | Jefferson, | Corsica, | | Freeport Lower limestone, | Brownish gray, brittle. |
| 169. | Jefferson, | Brockwayville, | N. B. Lane, | Johnston's cement bed, | Dark gray, hard, tough. |
| 170. | Jefferson, | Perrysville, | John Iler, | Johnston's cement bed, | Dark gray, hard, tough. |
| 171. | Jefferson, | Brockwayville, | C. Bovaird, | Ferriferous limestone, | Pearl gray, brittle. |
| 172. | Jefferson, | Sprankle Mills, | W. Hanna, | Ferriferous limestone, | Bluish gray, hard, fossil casts. |
| 173. | Jefferson, | Worthville, | A. Enty, | Ferriferous limestone, | Bluish gray, brittle, fossiliferous. |
| 174. | Jefferson, | Dowlingville, | S. Shields, | Ferriferous limestone, | Pearl gray, calcite, fossiliferous. |
| 175. | Jefferson, | Brookville, | | | Bluish gray, hard, tough, sandy. |
| 176. | Lancaster, | Lancaster, | McHoain & Brother, | | Quarry worked 50 yrs., 10,000 cu. yds. per year. |
| 177. | Lancaster, | Columbia, | Chestnut Hill Iron Ore Co., | | |
| 178. | Lancaster, | Pequa Valley, | S. D. McHoain, | | For building and land. |
| 179. | Lancaster, | Chickies, | Haldeman, | Siluro-Cambrian limestone Form. No. II, | Light bluish gray, hard and brittle, South quarry. |
| 180. | Lancaster, | Chickies, | Haldeman, | Siluro-Cambrian limestone Form. No. II, | Light brownish gray, hard and brittle, North quarry. |
| 181. | Lancaster, | Chickies, | Haldeman, | Siluro-Cambrian limestone Form. No. II, | Dark bluish gray, hard and tough, North quarry. |
| 182. | Lancaster, | Chickies, | Haldeman, | Siluro-Cambrian limestone Form. No. II, | Brownish gray, crumbling, North quarry. |
| 183. | Lawrence, | Wampum, | J. K. Shinn & Bro., | Ferriferous limestone, | Bluish gray, brittle, calcite. |
| 184. | Lawrence, | Mt. Jackson, | McCord, | Ferriferous limestone, | Pearl gray, brittle, calcite. |
| 185. | Lawrence, | New Castle, | Green Marquis & Johnson, | Ferriferous limestone, | Bluish gray, brittle, calcite. |
| 186. | Lawrence, | Croton, | Moffit, | Ferriferous limestone, | Bluish gray, brittle, calcite. |
| 187. | Lebanon, | Annville, | J. A. Bachman, | | Used for glass mfg. |
| 188. | Lebanon, | Heilmandale, | Mr. Heilman. | | |
| 189. | Lehigh, | Catasauqua, | Ed. Boyer. | | |
| 190. | Lehigh, | White Hall Station, | Mary Kohler, | Siluro-Cambrian limestone Form. No. II, | Brecciated limestone, blue and gray. |
| 191. | Lehigh, | Allentown, | Ephraim Wenner, | Siluro-Cambrian limestone Form. No. II, | Hard limestone, bluish gray, pyrites. |
| 192. | Lehigh, | Allentown, | Ephraim Wenner, | Siluro-Cambrian limestone Form. No. II, | Soft limestone, dark blue, laminated. |
| 193. | Lehigh, | Catasauqua, | Ed. Guth, | Siluro-Cambrian limestone Form. No. II, | Slatey, dark blue. |
| 194. | Lehigh, | Guth's Station, | Thomas Iron Co., | Siluro-Cambrian limestone Form. No. II, | Some quartz, bluish gray. |

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| 195. | Lehigh, | Ironton, | Ironton R. R. Co., | Siluro-Cambrian limestone Form. No. II, | Hard, compact, bluish gray. |
| 196. | Lehigh, | Alburtis, | Thomas Iron Co., | | Bluish gray. |
| 197. | Lehigh, | Alburtis, | Thomas Iron Co., | | Bluish gray, crystalline. |
| 198. | Lehigh, | Trexlertown, | Mrs. Kuhn, | | Bluish gray, siliceous. |
| 199. | Lehigh, | Trexlertown, | Franz, | | Dark blue, siliceous. |
| 200. | Lehigh, | Allentown, | | | Disintegrated. |
| 201. | Lehigh, | Allentown, | | | Fresh, 1½ in. under No. 200. |
| 202. | Lehigh, | Alburtis, | Ruths, Thos. Iron Co. | | |
| 203. | Lycoming, | Jersey Shore, Porter township, | Wilson, | Lewistown limestone No. VI, | Bluish gray, soft. |
| 204. | Lycoming, | Jersey Shore, Porter township, | Ferguson, | Lewistown limestone No. VI, | Bluish gray, hard, compact, calcite. |
| 205. | Lycoming, | Jersey Shore, Porter township, | Bailey, | Lewistown limestone No. VI, | Bluish gray, hard. |
| 206. | Mifflin, | Belleville, | D. Campbell, | Siluro-Cambrian limestone Form. No. II, | Fossiliferous, contains calcite. |
| 207. | Mifflin, | Belleville, | A. Campbell, | Siluro-Cambrian limestone Form. No. II, | Probably top of Calciferous, black and gray. |
| 208. | Mifflin, | Belleville, | A. Campbell, | Siluro-Cambrian limestone Form. No. II, | Bottom of Chazy, hard, light bluish gray. |
| 209. | Mifflin, | Belleville, | Greenwood Ore Bank, | Siluro-Cambrian limestone Form. No. II, | Magnesian limestone, contains calcite. |
| 210. | Monroe, | Bossardsville, | P. M. Hiller. | | |
| 211. | Montgomery, | Port Kennedy, | Todd & Son, | Dolomite stratum. | |
| 212. | Montgomery, | Whitemarsh township, | G. W. H. Corson, | | For building and lime. |
| 213. | Montgomery, | King of Prussia, | Schwayer & Liess, | | Carbonaceous matter 0.13. |
| 214. | Perry, | Newport, | | Chemung limestone, | Comminuted shells, siliceous matrix, reddish. |
| 215. | Perry, | Newport, | | Chemung limestone, | Comminuted shells, siliceous matrix, reddish. |
| 216. | Perry, | Newport, | | Chemung limestone, | Comminuted shells, siliceous matrix, reddish. |

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| 217. | Perry, | Mahonoy Valley, | Still, | Lewistown limestone, | Dark blue, brittle, slatey. |
| 218. | Perry, | Mahonoy Valley, | Still, | Lewistown limestone, | Bluish gray, brittle, fossiliferous, calcite. |
| 219. | Somerset, | Somerset, | Zimmerman, | Johnstown cement bed, | Bluish gray, compact, sandy. |
| 220. | Somerset, | Friedensburg, | Reitz, | Johnstown cement bed, | Bluish gray, compact, hard. |
| 221. | Somerset, | Stoystown, | Wilt, | Johnstown cement bed, | Bluish gray, compact. |
| 222. | Somerset, | Sipesville, | J. J. Pile, | Johnstown cement bed, | Bluish gray, compact, brittle. |
| 223. | Somerset, | Jenner Cross Roads, | J. W. Beam, | Johnstown cement bed, | Compact, upper bench of quarry. |
| 224. | Somerset, | Jenner Cross Roads, | J. W. Beam, | Johnstown cement bed, | Compact, middle bench of quarry. |
| 225. | Somerset, | Jenner Cross Roads, | J. W. Beam, | Johnstown cement bed, | Compact, lower bench of quarry. |
| 226. | Somerset, | Shade township, | Rodgers, | Johnstown cement bed, | Bluish gray, hard, sandy. |
| 227. | Somerset, | Davidsville, | Trevorrow, | Johnstown cement bed, | Bluish gray, brittle. |
| 228. | Somerset, | Scalp Level, | Weaver, | Johnstown cement bed, | Bluish gray, compact. |
| 229. | Somerset, | Salisbury, | S. S. Flickenger, | Little Pittsburgh limestone, | Slatey, contains coal, much pyrite. |
| 230. | Somerset, | Ursina, | Pittsburgh Coal, Coke & Iron Co., | Elk Lick limestone, | Bluish gray, compact. |
| 231. | Somerset, | Meyersdale, | Elias Yoder, | Elk Lick limestone, | Bluish gray, compact. |
| 232. | Somerset, | Jenner Cross Roads, | Peter Berkey, | Elk Lick limestone, | Bluish gray, compact. |
| 233. | Somerset, | Salisbury, | M. J. Beechy, | Redstone limestone, | Pearl gray, crystalline. |
| 234. | Somerset, | Buckstown, | Burkit, | ..... | Concretionary nodules of greenish limestone. |
| 235. | Somerset, | Forwardstown, | Harshberger, | ..... | Bluish black, compact, contains pyrites. |
| 236. | Somerset, | Meyersdale, | Keystone Coal and Mfg. Co., | Great limestone, | Bluish gray, hard compact, Fe as carbonate. |
| 237. | Somerset, | Meyersdale, | Saylor Hill, | Great limestone, | Bluish gray, brittle, compact, Fe as carbonate. |
| 238. | Somerset, | Meyersdale, | Saylor Hill, | Sewickly limestone, | Yellowish gray, brittle, compact, Fe as carbonate. |
| 239. | Somerset, | Salisbury, | J. M. Hayes, | Sewickly limestone, | Bluish gray, brittle, hard, Fe as carbonate. |
| 240. | Sullivan, | Millview, | Lucke, | Chemung Formation limestone No. VIII, | Fossiliferous, contains calcite, rose tinted, upper bench. |
| 241. | Sullivan, | Millview, | Lucke, | Chemung Formation limestone No. VIII, | Fossiliferous, contains calcite, rose tinted, lower bench. |
| 242. | Tioga, | Mansfield, | G. R. Wilson, | Chemung Formation limestone No. VIII, | Contains comminuted sea shells and shale. |
| 243. | Washington, | Canonsburg, | ..... | Great lower limestone division, | Fe reckoned as carbonate. |
| 244. | Washington, | Canonsburg, | ..... | Great lower limestone division, | Fe reckoned as carbonate. |
| 245. | Washington, | Canonsburg, | ..... | Great lower limestone division, | Fe reckoned as carbonate. |
| 246. | Washington, | Somerset, | ..... | Great lower limestone division, | Fe reckoned as carbonate. |
| 247. | Washington, | Washington, | ..... | Upper Washington limestone, | Fe reckoned as carbonate. |
| 248. | Wayne, | Cherry Ridge township, | ..... | Catskill limestone, | Reddish gray, brecciated. |
| 249. | Wayne, | Cherry Ridge township, | ..... | Catskill limestone, | Greenish gray, brecciated, contains malachite. |
| 250. | Wayne, | Oregon township, | ..... | Catskill limestone, | Greenish gray, siliceous. |
| 251. | Wayne, | Oregon township, | ..... | Catskill limestone, | Greenish gray, sandy. |
| 252. | Westmoreland, | Kelley's Station, | Wining & Cuisan, | Upper limestone, | Pearl gray, compact, brittle, calcite. |
| 253. | Westmoreland, | Salina, | Kier Bros., | Upper limestone, | Reddish gray, brittle. |

| Compilation number. | County. | Town. | Owner. | Geological Formation. | Remarks. |
|---|---|---|---|---|---|
| 254. | Westmoreland, | Mt. Pleasant, | Freeman, | | So-called "Black ore," sandy looking. |
| 255. | York, | Wrightsville, | Kerr Bros., | | For lime and fluxes. |
| 256. | York, | Dillsburg, | | | Greenish gray. |
| 257. | York, | Xenia P. O., | | | Greenish gray, contains manganese. |
| 258. | York, | | | | Conglomerate limestone. |
| 259. | York, | Seitzland, | | | White crystalline limestone. |
| 260. | York, | Wrightsville, | | | |
| 261. | York, | Mengis Mill Station, | Sprenkel, | Siluro-Cambrian limestone Form. No. II, | Greenish gray, and pink, compact and laminated. |
| 262. | York, | Mengis Mill Station, | Sprenkel, | Siluro-Cambrian limestone Form. No. II, | Bluish gray, contains magnetic oxid of Fe. |
| 263. | York, | Dillsburg, | Welty, | Mesozoic limestone, | Greenish gray, hard, tough, brecciated. |
| 264. | York, | Dillsburg, | Welty, | Mesozoic limestone, | Greenish gray, hard, tough, brecciated. |
| 265. | York, | Dillsburg, | Welty, | Mesozoic limestone, | Greenish gray, hard, tough, brecciated. |
| 266. | York, | Dillsburg, | Welty, | Mesozoic limestone, | Greenish gray, hard, tough, brecciated. |
| 267. | York, | Dillsburg, | Welty, | Mesozoic limestone, | Greenish gray, hard, tough, brecciated. |
| 268. | York, | Hanover, | Bittinger & Eberley. | | |
| 269. | York, | Wrightsville, | C. Kerr. | | |
| 270. | York, | Wrightsville, | C. Kerr. | | |
| 271. | York, | Wrightsville, | C. Kerr. | | |
| 272. | York, | Wrightsville, | C. Kerr. | | |
| 273. | York, | Wrightsville, | C. Kerr. | | |

| Compilation number. | Analyst. | No. of analysis. | References. | Insoluble matter. | Oxid of iron and alumina, $Fe_2O_3$ and $Al_2O_3$. | Carbonate of lime, $CaCO_3$. | Carbonate of magnesia, $MgCO_3$. | Sulfuric acid, $SO_3$. | Phosphoric acid, $P_2O_5$. | Other Constituents. | Undetermined. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Page. | | | | | | | | |
| 1. | ..... | 291 | 83 $M_3$ 1879-1880, 2d Geol. Surv. Pa.,. | 9,520 | 2,568 | 84.857 | 1.868 | ..... | 0.055* | ..... | 1.132 |
| 2. | ..... | 292 | 83 $M_3$ 1879-1880, 2d Geol. Surv. Pa.,. | 0.830 | 0.964 | 96.453 | 1.445 | ..... | 0.016* | ..... | 0.392 |
| 3. | ..... | 293 | 83 $M_3$ 1879-1880, 2d Geol. Surv. Pa.,. | 2.200 | 1.340 | 93.214 | 2.065 | ..... | 0.009* | ..... | 1.172 |
| 4. | ..... | 294 | 83 $M_3$ 1879-1880, 2d Geol. Surv. Pa.,. | 3.170 | 1.207 | 93.571 | 1.324 | ..... | 0.067* | ..... | 0.661 |
| 5. | ..... | 295 | 84 $M_3$ 1879-1880, 2d Geol. Surv. Pa.,. | 5.030 | 2.557 | 88.839 | 1.513 | ..... | 0.048* | ..... | 2.013 |
| 6. | ..... | 296 | 84 $M_3$ 1879-1880, 2d Geol. Surv. Pa.,. | 1.920 | 1.246 | 94.928 | 1.210 | ..... | 0.041* | ..... | 0.655 |
| 7. | ..... | 297 | 84 $M_3$ 1879-1880, 2d Geol. Surv. Pa.,. | 1.850 | 1.182 | 94.642 | 1.574 | ..... | 0.028* | ..... | 0.724 |
| 8. | ..... | 298 | 84 $M_3$ 1879-1880, 2d Geol. Surv. Pa.,. | 4.830 | 2.002 | 89.303 | 1.900 | ..... | 0.048* | ..... | 1.917 |
| 9. | ..... | 299 | 84 $M_3$ 1879-1880, 2d Geol. Surv. Pa.,. | 7.310 | 3.367 | 82.589 | 5.751 | ..... | 0.144* | ..... | 0.839 |
| 10. | ..... | 300 | 84 $M_3$ 1879-1880, 2d Geol. Surv. Pa.,. | 4.520 | 1.860 | 89.857 | 2.898 | ..... | 0.139* | ..... | 0.826 |
| 11. | ..... | 301 | 85 $M_3$ 1879-1880, 2d Geol. Surv. Pa.,. | 23.840 | 7.730 | 53.750 | 9.989 | ..... | 0.300* | ..... | 4.391 |
| 12. | ..... | 302 | 85 $M_3$ 1879-1880, 2d Geol. Surv. Pa.,. | 22.280 | 7.450 | 64.160 | 1.838 | ..... | 0.698* | ..... | 3.574 |
| 13. | ..... | 303 | 85 $M_3$ 1879-1880, 2d Geol. Surv. Pa.,. | 2.030 | 1.288 | 95.535 | 0.907 | 0.064 | 0.082 | $Mn_2O_3.2O, H_2O, .150$ | ..... |
| 14. | ..... | 304 | 85 $M_3$ 1879-1880, 2d Geol. Surv. Pa.,. | 0.790 | 1.462 | 96.007 | 1.498 | ..... | 0.078* | ..... | 0.165 |
| 15. | ..... | 305 | 86 $M_3$ 1879-1880, 2d Geol. Surv. Pa.,. | 2.300 | 1.383 | 94.721 | 1.044 | ..... | 0.108* | ..... | 0.444 |
| 16. | ..... | 306 | 86 $M_3$ 1879-1880, 2d Geol. Surv. Pa.,. | 2.110 | 0.930 | 95.567 | 1.422 | ..... | 0.080* | ..... | ..... |
| 17. | ..... | 307 | 86 $M_3$ 1879-1880, 2d Geol. Surv. Pa.,. | 2.100 | 2.089 | 94.185 | 1.483 | ..... | 0.071* | ..... | 0.072 |
| 18. | ..... | 308 | 86 $M_3$ 1879-1880, 2d Geol. Surv. Pa.,. | 3.420 | 1.667 | 93.246 | 1.740 | ..... | 0.074* | ..... | ..... |
| 19. | ..... | 309 | 86 $M_3$ 1879-1880, 2d Geol. Surv. Pa.,. | 3.220 | 1.713 | 93.292 | 0.968 | ..... | 0.108* | ..... | 0.699 |
| 20. | ..... | 947 | 298 $M_2$ 1876-8, 2d Geol. Surv. Pa.,... | 0.370 | 1.000 | 96.785 | 1.278 | 0.150* | 0.066* | ..... | 0.351 |
| 21. | ..... | 802a | 301 $M_2$ 1876-8, 2d Geol. Surv. Pa.,... | 2.500 | 0.842 | 95.664 | 1.547 | 0.256* | 0.034* | ..... | ..... |
| 22. | ..... | 802b | 301 $M_2$ 1876-8, 2d Geol. Surv. Pa.,... | 3.000 | 0.644 | 95.089 | 1.581 | 0.073* | 0.046* | ..... | ..... |
| 23. | ..... | 802c | 301 $M_2$ 1876-8, 2d Geol. Surv. Pa.,... | 3.020 | 0.570 | 95.571 | 1.521 | 0.068* | 0.021* | ..... | ..... |
| 24. | ..... | 648 | 302 $M_2$ 1876-8, 2d Geol. Surv. Pa..... | 1.800 | †0.054 | 95.251 | 2.265 | 0.133* | 0.007* | $FeCO_3$ 0.745, ..... | ..... |
| 25. | ..... | 649 | 302 $M_2$ 1876-8, 2d Geol. Surv. Pa.,... | 1.615 | †0.035 | 96.164 | 1.589 | 0.175* | 0.011* | $FeCO_3$ 0.615, ..... | ..... |
| 26. | ..... | 650 | 302 $M_2$ 1876-8, 2d Geol. Surv. Pa.,... | 10.850 | †0.043 | 84.782 | 3.859 | 0.133* | 0.009* | $FeCO_3$ 0.534, ..... | ..... |
| 27. | ..... | ..... | ..... | 2.000 | ..... | 96.000 | 2.000 | ..... | trace | ..... | ..... |
| 28. | ..... | ..... | ..... | ..... | ..... | 98.000 | ..... | ..... | ..... | ..... | 2.00 |
| 29 | ..... | ..... | ..... | 1.400 | 1.600 | 94.480 | 2.570 | ..... | trace | ..... | ..... |
| 30. | ..... | ..... | ..... | 1.600 | 2.600 | 92.900 | 2.880 | ..... | trace | ..... | ..... |
| 31. | S. S. Hartranft,..... | 786 | 306 $M_2$ 1876-8, 2d Geol. Surv. Pa.,... | 0.910 | 0.264 | 94.980 | 3.866 | 0.133* | 0.026* | ..... | ..... |
| 32. | ..... | 807 | 306 $M_2$ 1876-8, 2d Geol. Surv. Pa.,... | 3.210 | 1.126 | 78.196 | 17.510 | 0.213* | 0.034* | ..... | ..... |
| 33. | ..... | 964a | 306 $M_2$ 1876-8, 2d Geol. Surv. Pa ,... | 8.570 | 1.850 | 78.176 | 10.746 | 0.373* | 0.066* | ..... | 0.219 |

*Recalculated. †$Al_2O_3$ only.

| Compilation number. | Analyst. | No. of analysis. | References. | Insoluble matter. | Oxid of iron and alumina, $Fe_2O_3$ and $Al_2O_3$. | Carbonate of lime, $CaCO_3$. | Carbonate of magnesia, $MgCO_3$. | Sulfuric acid, $SO_3$. | Phosphoric acid, $P_2O_5$. | Other Constituents. | Undetermined. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Page. | | | | | | | | |
| 34. | ..... | 964b | 306 $M_2$ 1876-8, 2d Geol. Surv. Pa.,... | 4.380 | 0.640 | 91.892 | 2.875 | 0.243* | 0.050* | ..... | ..... |
| 35. | ..... | 964c | 306 $M_2$ 1876-8, 2d Geol. Surv. Pa.,... | 1.330 | 0.234 | 64.671 | 44.180 | 0.005* | 0.007* | ..... | ..... |
| 36. | ..... | 1,011a | 306 $M_2$ 1876-8, 2d Geol. Surv. Pa.,... | 5.880 | 1.682 | 90.389 | 2.245 | ..... | ..... | Fe as carbonate, | ..... |
| 37. | ..... | 1,011b | 306 $M_2$ 1876-8, 2d Geol. Surv. Pa.,... | 3.620 | 0.189 | 92.115 | 4.234 | ..... | ..... | Fe as carbonate, | ..... |
| 38. | ..... | 85 | 307 $M_2$ 1876-8, 2d Geol. Surv. Pa.,... | 10.380 | 2.850 | 48.030 | 37.670 | 1.158* | 0.096* | ..... | 0.567 |
| 39. | ..... | 86 | 307 $M_2$ 1876-8, 2d Geol. Surv. Pa.,... | 29.100 | 1.190 | 53.870 | 41.320 | 0.113* | 0.030* | ..... | ..... |
| 40. | ..... | 334 | 299 $M_2$ 1876-8, 2d Geol. Surv. Pa.,... | 18.010 | 7.041 | 73.250* | 2.329* | 0.167 | 0.279 | ..... | ..... |
| 41. | Brook Iron Co., ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... |
| 42. | W. C. Henderson, ... | ..... | ..... | 0.850 | 0.900 | 54.240 | 43.960 | ..... | ..... | ..... | 0.300 |
| 43. | ..... | ..... | 80 Catalogue of Exhibits, ..... | ..... | 1.400 | 94.440 | ..... | ..... | ..... | ..... | 1.890 |
| 44. | Clement G. Smith, .. | ..... | ..... | 2.10 | †0.510 | 73.730 | 20.100* | ..... | ..... | $SiO_2$, 1.67, ..... | ..... |
| 45. | ..... | ..... | ..... | 2.770 | †1.520 | 63.530 | 30.260* | ..... | ..... | $SiO_2$, 2.26, ..... | ..... |
| 46. | ..... | ..... | ..... | trace | trace | 94.500 | trace | ..... | ..... | $SiO_2$, trace, ..... | 5.500 |
| 47. | ..... | ..... | ..... | 3.800 | 0.900 | 75.500 | 19.500 | ..... | trace | ..... | 2.780 |
| 48 | ..... | ..... | ..... | 2.770 | 1.823 | 93.482 | 1.544 | 0.075* | 0.108* | ..... | 0.198 |
| 49. | ..... | 596 | 297 MM 1876-8, 2d Geol. Surv. Pa.,... | 7.080 | 2.824 | 88.464 | 1.445 | 0.243* | 0.066* | ..... | 0.428 |
| 50. | ..... | 599 | 297 MM 1876-8, 2d Geol. Surv. Pa.,... | 4.780 | 1.291 | 91.607 | 1.566 | 0.725* | 0.069* | ..... | ..... |
| 51. | ..... | 600 | 297 MM 1876-8, 2d Geol. Surv. Pa.,... | 4.800 | 1.589 | 91.089 | 1.587 | 0.118* | 0.092* | ..... | 0.525 |
| 52. | ..... | 555 | 297 MM 1876-8, 2d Geol. Surv. Pa.,... | 2.310 | 4.503 | 72.321 | 20.591 | 0.023* | 0.108* | $Mn_2O_3$ 433, .....* | ..... |
| 53. | ..... | 278 | 80 $M_3$ 1879-80, 2d Geol. Surv. Pa.,... | 8.410 | 0.571 | 86.357 | 5.236 | 0.035* | 0.030* | ..... | ..... |
| 54. | Walton Quarries, ... | 279 | 80 $M_3$ 1879-80, 2d Geol. Surv. Pa.,... | 1.370 | 0.360 | 97.732 | 0.908 | ..... | ..... | ..... | ..... |
| 55. | Walton Quarries, ... | 340 | MM 1876-8, 2d Geol. Surv. Pa.,... | 1.670 | 0.900 | 95.121 | 1.952 | ..... | ..... | ..... | 0.357 |
| 56. | Walton Quarries, ... | 341 | MM 1876-8, 2d Geol. Surv. Pa.,... | 0.620 | 0.390 | 98.912 | 1.134 | ..... | ..... | ..... | ..... |
| 57. | Walton Quarries, ... | 334 | MM 1876-7, 2d Geol. Surv. Pa.,... | 3.820 | 0.580 | 95.372 | 1.339 | ..... | ..... | ..... | ..... |
| 58. | Walton Quarries, ... | 335 | MM 1876-8, 2d Geol. Surv. Pa.,... | 15.870 | 3.020 | 54.134 | 28.123 | ..... | ..... | ..... | ..... |
| 59. | Walton Quarries, ... | 334 | MM 1876-8, 2d Geol. Surv. Pa.,... | 12.500 | 2.630 | 52.025 | 33.657 | ..... | ..... | ..... | ..... |
| 60. | Walton Quarries, ... | 335 | MM 1876-8, 2d Geol. Surv. Pa.,... | 6.660 | 0.800 | 60.018 | 32.828 | ..... | ..... | ..... | ..... |
| 61. | Walton Quarries, ... | 336 | MM 1876-8, 2d Geol. Surv. Pa.,... | 7.790 | 1.090 | 62.036 | 29.423 | ..... | ..... | ..... | ..... |
| 62. | J. A. Fries, ..... | 337 | MM 1876-8, 2d Geol. Surv. Pa.,... | 6.510 | ..... | 87.590 | 2.520 | ..... | ..... | ..... | 8.710 |
| 63. | J. A. Fries, ..... | 10,640 | Pa. Expt. Station records, .... .... | 5.960 | ..... | 91.210 | 2.210 | ..... | ..... | ..... | 4.260 |
| 64. | J. A. Fries, ..... | 10,641 | Pa. Expt. Station records, .... .... | 16.070 | ..... | 66.960 | 2.230 | ..... | ..... | ..... | 14.740 |
| 65. | J. A. Fries, ..... | 10,642 | Pa. Expt. Station records, ..... | 5.890 | ..... | 87.730 | 1.620 | ..... | ..... | ..... | 0.620 |
| 66. | W. S. Sweetser, .... | 10,643 | Pa. Expt. Station records, ..... | 6.640 | ..... | 84.830 | ..... | ..... | ..... | ..... | 3.380 |
| | | 26,169 | | | | | | | | | |

†$Al_2O_3$ only.

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 67. | W. S. Sweetser, .... | 24,170 | Pa. Expt. Station records, ..... | 11.680 | ..... | 75.030 | ..... | ..... | ..... | 13.290 |
| 68. | C. P. Beistle, ..... | 30,108 | Pa. Expt. Station records, ..... | 1.430 | ..... | 97.590 | ..... | ..... | 0.040 | 0.950 |
| 69. | A. S. McCreath, ..... | ..... | 76 M 1874, 2d Geol. Surv. Pa., ..... | 18.730 | ..... | 42.941 | 22.764 | 1.500* | 0.114* | 13.951 |
| 70. | A. S. McCreath, ..... | ..... | 76 M Pa., 1874, 2d Geol. Survey Pa., | 23.530 | ..... | 51.153 | 13.265 | trace | 0.657* | 11.495 |
| 71. | J. Hartshorne, ..... | 1,012a | 307 MM 2d G. S., 1876-8, ..... | 0.540 | 0.203 | 97.890 | 1.285 | ..... | ..... | 0.082 |
| 72. | J. Hartshorne, ..... | 1,012b | 307 MM 2d G. S., 1876-8, ..... | 0.390 | 0.320 | 98.322 | 1.170 | ..... | ..... | ..... |
| 73. | J. Hartshorne, ..... | 1,012c | 307 MM 2d G. S., 1876-8, ..... | 0.815 | 0.377 | 97.532 | 1.210 | ..... | ..... | 0.066 |
| 74. | ..... | ..... | ..... | 5.000* | ..... | 75.000* | 20.000 | ..... | ..... | ..... |
| 75. | ..... | ..... | 79 Catalogue of Exhibits, ..... | 36.270 | 1.910 | 58.520 | 3.870 | ..... | Soluble $SiO_2$, 0.07, | ..... |
| 76. | ..... | ..... | 79 Catalogue of Exhibits, ..... | 4.650 | 0.390 | 83.390 | 12.420 | ..... | Soluble $SiO_2$, 0.04, | ..... |
| 77. | ..... | ..... | 81 Catalogue of Exhibits, ..... | 1.610 | ..... | 58.010 | 40.389 | ..... | ..... | ..... |
| 78. | ..... | 272 | 79 $M_3$ 2d G. S., 1879-80, ..... | 1.950 | 0.613 | 54.071 | 43.309 | 0.033* | 0.007* | ..... | 0.017 |
| 79. | ..... | 310 | 86 $M_3$ 2d G. S., 1879-80, ..... | 1.800 | 0.765 | 93.803 | 2.270 | ..... | 0.018* | ..... | 1.344 |
| 80. | ..... | 311 | 86 $M_3$ 2d G. S., 1879-80, ..... | 5.320 | 1.365 | 82.678 | 8.248 | ..... | 0.051* | ..... | 2.338 |
| 81. | ..... | 312 | 86 $M_3$ 2d G. S., 1879-80. ..... | 7.940 | 2.736 | 82.000 | 6.311 | ..... | 0.034* | ..... | 0.979 |
| 82. | ..... | 313 | 87 $M_3$ 2d G. S., 1879-80, ..... | 2.190 | 1.310 | 95.232 | 0.407 | ..... | 0.139* | ..... | 0.722 |
| 83. | ..... | 314 | 87 $M_3$ 2d G. S., 1879-80, ..... | 1.960 | 1.050 | 95.532 | 0.930 | ..... | 0.160* | ..... | 0.368 |
| 84. | ..... | 315 | 87 $M_3$ 2d G. S., 1879-80. ..... | 1.780 | 1.529 | 95.196 | 1.265 | ..... | 0.185* | ..... | 0.045 |
| 85. | ..... | 316 | 87 $M_3$ 2d G. S., 1879-80, ..... | 1.110 | 0.867 | 96.428 | 1.202 | ..... | 0.053* | ..... | 0.340 |
| 86. | ..... | 370 | 295 MM 2d G. S., 1876-8, ..... | 27.873 | 3.390† | 34.301 | 21.650 | ..... | 0.112* | $FeS_2$ 1.268, ..... | 2.706 |
| 87. | A. S. McCreath, ..... | ..... | 77 M 2d G. S., 1874-5, ..... | 2.070 | ..... | 93.810 | 1.710 | 0.129* | 0.018* | ..... | 2.263 |
| 88. | ..... | 351 | 93 $M_3$ 2d G. S., 1879-80, ..... | 2.660 | ..... | 95.071 | 1.044 | ..... | ..... | $FeCO_3$ .261, $CaSO_4$ .744 $H_2O$ & organic matter, .220, | ..... |
| 89. | ..... | 91a | 365 MM 2d G. S. 1876-8, ..... | 1.052‡ | 0.190 | 87.675* | 1.725* | 0.222 | 0.023 | $FeS_2$ 0.429, $K_2O$ .0116, $H_2O$ 2.190, Carb. matter 6.510, | ..... |
| 90. | ..... | 780a | 310 MM 2d G. S., 1876-8, ..... | 4.300 | 0.363 | 86.125 | 8.861 | 0.340* | 0.087* | ..... | ..... |
| 91. | ..... | 780b | 310 MM 2d G. S., 1876-8. ..... | 2.508 | 0.600 | 90.625 | 6.167 | 0.200* | 0.050* | ..... | ..... |
| 92. | ..... | 1,018a | 311 MM 2d G. S., 1876-8, ..... | 4.250 | ..... | 65.750 | 28.436 | ..... | 0.011* | ..... | 1.549 |
| 93. | ..... | 1,018b | 311 MM 2d G. S., 1876-8, ..... | 7.450 | ..... | 79.500 | 11.730 | ..... | trace | ..... | 1.320 |
| 94. | ..... | 1,018c | 311 MM 2d G. S., 1876-8. ..... | 2.550 | ..... | 92.000 | 4.540 | ..... | trace | ..... | 0.910 |
| 95. | ..... | 1,018d | 311 MM 2d G. S., 1876-8, ..... | 2.750 | ..... | 69.250 | 26.250 | ..... | trace | ..... | 1.365 |
| 96. | ..... | 335 | 91 $M_3$ 2d G. S., 1879-80, ..... | 12.290 | 3.610 | 80.357 | 1.619 | ..... | 0.197* | ..... | 1.927 |
| 97. | ..... | 336 | 91 $M_3$ 2d G. S., 1879-80, ..... | 6.540 | 2.750 | 81.875 | 7.189 | ..... | 0.151* | ..... | 1.495 |
| 98. | ..... | 337 | 91 $M_3$ 2d G. S., 1879-80, ..... | 13.680 | 4.835 | 69.257 | 9.308 | ..... | 0.176* | ..... | 2.641 |
| 99. | ..... | 338 | 91 $M_3$ 2d G. S., 1879-80, ..... | 21.250 | 7.940 | 57.321 | 8.854 | ..... | 0.087* | ..... | 4.548 |
| 100. | ..... | 339 | 91 $M_3$ 2d G. S., 1879-80. ..... | 2.390 | 2.205 | 86.910 | 6.659 | ..... | 0.039* | ..... | 1.797 |
| 101. | ..... | 340 | 91 $M_3$ 2d G. S., 1879-80, ..... | 7.370 | 2.610 | 86.214 | 1.785 | ..... | 0.115* | ..... | 1.906 |
| 102. | ..... | 341 | 91 $M_3$ 2d G. S., 1879-80, ..... | 3.370 | 1.710 | 91.785 | 1.808 | ..... | 0.074* | ..... | 1.253 |
| 103. | ..... | 347 | 92 $M_3$ 2d G. S., 1879-80, ..... | 36.860 | 7.040 | 50.357 | 2.467 | ..... | 0.124* | ..... | 3.152 |
| 104. | ..... | 342 | 92 $M_3$ 2d G. S., 1879-80, ..... | 61.670 | 3.830 | 27.857 | 0.983 | ..... | 0.142* | ..... | 5.518 |
| 105. | ..... | 343 | 92 $M_3$ 2d G. S., 1879-80, ..... | 38.950 | 3.030 | 54.553 | 1.135 | ..... | 0.238* | ..... | 2.094 |
| 106. | ..... | 344 | 92 $M_3$ 2d G. S., 1879-80, ..... | 41.690 | 3.650 | 49.732 | 1.331 | ..... | 0.545* | ..... | 3.052 |
| 107. | ..... | 345 | 92 $M_3$ 2d G. S., 1879-80. ..... | 1.630 | 1.638 | 94.357 | 1.634 | ..... | 0.071* | ..... | 0.670 |
| 108. | ..... | 346 | 92 $M_3$ 2d G. S., 1879-80. ..... | 2.200 | 1.625 | 94.107 | 1.369 | ..... | 0.144* | ..... | 0.554 |
| 109. | ..... | 348 | 92 $M_3$ 2d G. S., 1879-80. ..... | 8.390 | 3.422 | 85.714 | 1.171 | ..... | 0.158* | ..... | 1.145 |
| 110. | ..... | 349 | 92 $M_3$ 2d G. S., 1879-80, ..... | 50.670 | 10.070 | 36.785 | 1.408 | ..... | ..... | ..... | 1.067 |
| 111. | ..... | 350 | 93 $M_3$ 2d G. S., 1879-80, ..... | 15.980 | 3.680 | 76.143 | 1.740 | ..... | ..... | ..... | 2.457 |
| 112. | A. S. McCreath, ..... | ..... | 77 M 2d G. S., 1874-5. ..... | 16.130 | ..... | 66.912 | 9.836 | 0.295* | 0.165* | ..... | 16.662 |
| 113. | A. S. McCreath, ..... | ..... | 77 M 2d G. S., 1874-5. ..... | 53.330 | ..... | 36.764 | 2.011 | trace | 0.071* | ..... | 7.914 |
| 114. | W. S. Sweetser, ..... | 29,982 | Pa. Expt. Station records, ..... | 5.650 | ..... | 89.870 | 1.320 | ..... | ..... | .... ..... | 3.160 |

*Recalculated. †$Al_2O_3$ only.

| Compilation number. | Analyst. | No. of analysis. | References. | Insoluble matter. | Oxid of iron and alumina, $Fe_2O_3$ and $Al_2O_3$. | Carbonate of lime, $CaCO_3$. | Carbonate of magnesia, $MgCO_3$. | Sulfuric acid, $SO_3$. | Phosphoric acid, $P_2O_5$. | Other Constituents. | Undetermined. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 115. | ..... | 41 | 287 MM 2d G. S., 1876-8, ..... | 10.770 | 2.200 | 80.647 | 2.217 | 0.052 | 0.066 | $FeS_2$ 1.125 $H_2O$ 1.010 Carbon. matter,.. | 1.250 |
| 116. | ..... | 594 | 289 MM 2d G. S., 1876-8, ..... | 9.460 | 5.990 | 66.471 | 17.711 | 0.200* | 0.110* | ..... | 0.058 |
| 117. | ..... | 595 | 290 MM 2d G. S., 1876-8, ..... | 7.360 | 0.135† | 87.868 | 1.733 | 0.265* | 0.115* | $FeCO_3$ 1.914, ..... | 0.510 |
| 118. | ..... | 334 | 90 $M_3$ 2d G. S., 1879-80, ..... | 55.160 | 2.120 | 40.642 | 1.172 | ..... | 0.041* | ..... | 0.865 |
| 119. | ..... | 280 | 80 $M_3$ 2d G. S., 1879-80, ..... | 8.840 | 0.806 | 89.178 | 0.961 | ..... | 0.115* | ..... | 0.100 |
| 120. | ..... | 281 | 80 $M_3$ 2d G. S., 1879-80, ..... | 2.160 | 0.941 | 54.393 | 42.694 | ..... | 0.030* | ..... | ..... |
| 121. | ..... | 282 | 81 $M_3$ 2d G. S., 1879-80, ..... | 4.090 | 0.543 | 51.743 | 43.436 | 0.028* | 0.030* | ..... | 0.130 |
| 122. | ..... | 283 | 81 $M_3$ 2d G. S., 1879-80, ..... | 0.980 | 0.260 | 97.321 | 1.286 | ..... | 0.011* | ..... | 0.142 |
| 123. | ..... | 284 | 81 $M_3$ 2d G. S., 1879-80, ..... | 1.760 | 0.700 | 67.257 | 30.702 | ..... | 0.016* | ..... | ..... |
| 124. | ..... | 285 | 82 $M_3$ 2d G. S., 1879-80, ..... | 29.640 | 6.760 | 47.375 | 15.581 | ..... | ..... | ..... | 0.644 |
| 125. | ..... | ..... | 80 Catalogue of Exhibits, ..... | ..... | 0.800 | 92.950* | 2.070* | ..... | 0.020* | ..... | 2.910 |
| 126. | ..... | 560 | 302 MM 2d G. S., 1876-8, ..... | 5.700 | 0.123† | 90.904 | 2.162 | 0.203* | 0.023* | $FeCO_3$ 1.642, ..... | ..... |
| 127. | D. McCreath,..... | 527 | 302 MM 2d G. S., 1876-8, ..... | 2.330 | 0.697 | 94.035 | 1.965 | 0.140* | 0.027* | Fe as carbonate,.... | 0.806 |
| 128. | D. McCreath,..... | 528 | 302 MM 2d G. S., 1876-8, ..... | 5.040 | 1.139 | 91.125 | 1.572 | 0.075* | 0.032* | Fe as carbonate,.... | 1.017 |
| 129. | D. McCreath,..... | 532 | 303 MM 2d G. S., 1876-8, ..... | 5.300 | 1.783 | 89.292 | 2.557 | 0.148* | 0.062* | Fe as carbonate,.... | 0.858 |
| 130. | D. McCreath,..... | 534 | 303 MM 2d G. S., 1876-8, ..... | 49.030 | 1.667 | 47.300 | 2.011 | 0.365* | 0.062* | Fe as carbonate,.... | ..... |
| 131. | ..... | 536 | 303 MM 2d G. S., 1876-8, ..... | 8.150‡ | 1.260† | 70.557* | 18.099* | ..... | ..... | $FeCO_3$* 1.027,..... | 0.907 |
| 132. | ..... | 561 | 303 MM 2d G. S., 1876-8, ..... | 5.320 | 0.550 | 84.018* | 9.434* | ..... | ..... | $FeCO_3$*. $H_2O$.0.20,. | ..... |
| 133. | ..... | 535 | 303 MM 2d G. S., 1876-8, ..... | 33.220 | 14.066 | 25.198* | 19.638* | ..... | ..... | $FeCO_3$* 0.927, $H_2O$. 1.005, ..... | 1.492 |
| 134. | S. S. Hartranft,..... | 785 | 366 MM 2d G. S., 1876-8, ..... | 8.230 | 1.439 | 88.687 | 1.850 | 0.410* | 0.009* | ..... | ..... |
| 135. | S. S. Hartranft,..... | 950 | 367 MM 2d G. S., 1876-8, ..... | 42.460 | ‖4.536 | 52.571 | 2.081 | 0.140* | 0.270* | ..... | ..... |
| 136. | S. S. Hartranft,..... | 951 | 367 MM 2d G. S., 1876-8, ..... | 34.640 | 5.179 | 46.232 | 2.560 | 0.140* | 0.387* | ..... | 10.862 |
| 137. | ..... | 562 | 299 MM 2d G. S., 1876-8, ..... | 4.640 | 0.180† | 92.323 | 1.089 | 0.085* | 0.032* | $FeCO_3$ 0.683, ..... | 0.968 |
| 138. | ..... | 764 | 289 MM 2d G. S., 1876-8, ..... | 10.327 | 2.830 | 82.768 | 2.875 | 0.390* | 0.025* | ..... | 0.785 |
| 139. | ..... | 761 | 292 MM 2d G. S., 1876-8, ..... | 6.021 | 3.220 | 84.125 | 5.198 | 0.183* | 0.032* | ..... | 1.221 |
| 140. | ..... | 773 | 292 MM 2d G. S., 1876-8, ..... | 9.150 | 2.120 | 84.407 | 2.800 | 0.470* | 0.041* | ..... | 1.012 |
| 141. | ..... | 771 | 292 MM 2d G. S., 1876-8, ..... | 5.430 | 1.700 | 89.821 | 1.801 | 0.333* | 0.062* | ..... | 0.853 |
| 142. | ..... | 774 | 292 MM 2d G. S., 1876-8, ..... | 14.980 | 4.190 | 72.264 | 6.493 | 0.170* | 0.066* | ..... | 1.837 |
| 143. | ..... | 769 | 292 MM 2d G. S., 1876-8, ..... | 27.230 | 6.920 | 54.768 | 8.627 | 0.280* | 0.039* | ..... | 2.126 |
| 144. | ..... | 765 | 298 MM 2d G. S., 1876-8, ..... | 2.090 | 2.630 | 92.857 | 1.589 | 0.468* | 0.080* | ..... | 0.886 |
| 145. | ..... | 770 | 366 MM 2d G. S., 1876-8, ..... | 16.540 | 5.710 | 65.892 | 9.686 | 0.730* | 0.037* | ..... | 1.405 |
| 146. | ..... | 766 | 293 MM 2d G. S., 1876-8, ..... | 8.210 | 1.960 | 88.232 | 1.371 | 0.120* | 0.039* | ..... | 0.067 |
| 147. | ..... | 762 | 293 MM 2d G. S., 1876-8, ..... | 5.502 | 2.630 | 82.321 | 8.021 | 0.255* | 0.039* | ..... | 1.232 |
| 148. | ..... | 768 | 294 MM 2d G. S., 1876-8, ..... | 32.790 | 4.360† | 36.214 | 16.883 | 0.140* | 0.128* | $FeCO_3$ 8.078, ..... | 1.407 |

†$Al_2O_3$ only. ‡$SiO_2$ only. ‖$Fe_2O_3$ only.

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 149. | ..... | 775 | 294 MM 2d G. S., 1876-8, ..... | 15.060 | 7.380 | 58.750 | 16.005 | 0.103* | 0.195* | ..... | | 2.507 |
| 150. | ..... | 767 | 294 MM 2d G. S., 1876-8, ..... | 13.790 | 3.540 | 78.768 | 2.421 | 0.243* | 0.041* | ..... | | 1.197 |
| 151. | ..... | ..... | 288 MM 2d G. S., 1876-8, ..... | 12.160 | 3.020 | 79.821 | 3.601 | 0.293* | 0.041* | ..... | | 1.064 |
| 152. | ..... | 20,910 | Pa. Expt. Station Records, ..... | 36.060 | ..... | 59.020 | 1.220 | ..... | ..... | ..... | | 3.700 |
| 153. | ..... | 20,911 | Pa. Expt. Station Records, ..... | 41.940 | ..... | 52.970 | 1.090 | ..... | ..... | ..... | | 5.000 |
| 154. | ..... | 20,912 | Pa. Expt. Station Records, ..... | 20.910 | ..... | 21.590 | 2.920 | ..... | ..... | ..... | | 54.580 |
| 155. | A. N. Diehl, ..... | 32,454 | Pa. Expt. Station Records, ..... | 4.860 | 3.100 | 83.880 | 8.190 | ..... | ..... | ..... | | ..... |
| 156. | A. N. Diehl, ..... | 32,455 | Pa. Expt. Station Records, ..... | 11.450 | 1.250 | 83.690 | 2.760 | ..... | ..... | ..... | | 0.800 |
| 157. | A. N. Diehl, ..... | 32,456 | Pa. Expt. Station Records, ..... | 13.910 | 2.650 | 76.120 | 6.300 | ..... | ..... | ..... | | 0.770 |
| 158. | C. P. Beistle, ..... | 32,412 | Pa. Expt. Station Records, ..... | 2.160 | ..... | 95.030 | ..... | ..... | ..... | ..... | | 2.160 |
| 159. | ..... | 317 | 87 $M_3$ 2d G. S., 1879-80, ..... | 2.390 | 1.530 | 92.500 | 2.497 | ..... | 0.053* | ..... | | 1.030 |
| 160. | ..... | 318 | 87 $M_3$ 2d G. S., 1879-80, ..... | 9.780 | 4.230 | 75.357 | 9.330 | ..... | 0.039* | ..... | | 1.264 |
| 161. | ..... | 319 | 87 $M_3$ 2d G. S., 1879-80, ..... | 11.780 | 3.790 | 77.143 | 4.691 | ..... | 0.167* | ..... | | 2.429 |
| 162. | ..... | 320 | 88 $M_3$ 2d G. S., 1879-80, ..... | 6.170 | 2.140 | 89.107 | 1.611 | ..... | 0.055* | ..... | | 0.917 |
| 163. | ..... | 321 | 88 $M_3$ 2d G. S., 1879-80, ..... | 16.660 | 7.250 | 48.571 | 23.762 | ..... | 0.074* | ..... | | 3.683 |
| 164. | ..... | 322 | 88 $M_3$ 2d G. S., 1879-80, ..... | 3.480 | 1.285 | 90.000 | 2.860 | ..... | 0.025* | ..... | | 2.350 |
| 165. | ..... | 323 | 88 $M_3$ 2d G. S., 1879-80, ..... | 3.130 | 1.312 | 91.875 | 2.421 | ..... | 0.028* | ..... | | 1.234 |
| 166. | ..... | 324 | 88 $M_3$ 2d G. S., 1879-80, ..... | 6.770 | 1.740 | 88.928 | 1.589 | ..... | 0.053* | ..... | | 0.920 |
| 167. | ..... | 325 | 88 $M_3$ 2d G. S., 1879-80, ..... | 8.400 | 2.170 | 87.035 | 1.558 | ..... | 0.131* | ..... | | 0.706 |
| 168. | ..... | 326 | 88 $M_3$ 2d G. S., 1879-80, ..... | 2.070 | 2.320 | 92.857 | 1.680 | ..... | 0.044* | ..... | | 1.029 |
| 169. | ..... | 327 | 89 $M_3$ 2d G. S., 1879-80, ..... | 33.900 | 7.790 | 51.410 | 3.962 | ..... | 0.076* | ..... | | 2.862 |
| 170. | ..... | 328 | 89 $M_3$ 2d G. S., 1879-80, ..... | 8.020 | 4.653 | 82.393 | 1.891 | ..... | 0.687* | ..... | | 2.356 |
| 171. | ..... | 329 | 89 $M_3$ 2d G. S., 1879-80, ..... | 1.910 | 1.315 | 94.392 | 1.702 | ..... | 0.071* | ..... | | 0.610 |
| 172. | ..... | 330 | 89 $M_3$ 2d G. S., 1879-80, ..... | 2.040 | 1.310 | 93.643 | 1.816 | ..... | 0.069* | ..... | | 1.122 |
| 173. | ..... | 331 | 89 $M_3$ 2d G. S., 1879-80, ..... | 1.300 | 0.990 | 96.428 | 0.908 | ..... | 0.078* | ..... | | 0.296 |
| 174. | ..... | 332 | 90 $M_3$ 2d G. S., 1879-80, ..... | 1.280 | 0.780 | 96.578 | 0.832 | ..... | 0.085* | ..... | | 0.445 |
| 175. | ..... | 333 | 90 $M_3$ 2d G. S., 1879-80, ..... | 51.450 | 4.760 | 39.428 | 1.816 | ..... | 0.094* | ..... | | 2.452 |
| 176. | ..... | ..... | 78 Catalogue of Exhibits, ..... | 3.200 | ..... | 59.520* | 36.920* | ..... | ..... | ..... | | 3.600 |
| 177. | ..... | ..... | 79 Catalogue of Exhibits, ..... | 7.000 | ..... | 86.000 | 7.000 | ..... | ..... | ..... | | ..... |
| 178. | ..... | ..... | 80 Catalogue of Exhibits, ..... | ..... | ..... | ..... | 36.900 | ..... | ..... | ..... | | 0.360 |
| 179. | ..... | 779 | 309 MM 2d G. S., 1876-8, ..... | 0.436 | 0.517 | 54.750 | 44.204 | 0.028* | 0.023* | ..... | | 0.042 |
| 180. | ..... | 778a | 309 MM 2d G. S., 1876-8, ..... | 0.847 | 0.304 | 55.104 | 43.602 | 0.058* | 0.037* | ..... | | 0.048 |
| 181. | ..... | 778b | 309 MM 2d G. S., 1876-8, ..... | 1.926 | 0.869 | 53.517 | 43.522 | 0.053* | 0.032* | ..... | | 0.081 |
| 182. | ..... | 778c | 309 MM 2d G. S., 1876-8, ..... | 7.699 | 0.731 | 50.339 | 41.143 | 0.075* | 0.066* | ..... | | ..... |
| 183. | ..... | 747 | 297 MM 2d G. S., 1876-8, ..... | 2.790 | 0.805 | 94.214 | 1.732 | 0.413* | 0.046* | ..... | | ..... |
| 184. | ..... | 748 | 297 MM 2d G. S., 1876-8, ..... | 1.970 | 0.632 | 95.768 | 1.097 | 0.220* | 0.039* | ..... | | 0.274 |
| 186. | ..... | 746 | 297 MM 2d G. S., 1876-8, ..... | 3.070 | 1.563 | 93.340 | 1.460 | 0.308* | 0.108* | ..... | | 0.151 |
| 187. | ..... | ..... | 297 MM 2d G. S., 1876-8, ..... | 2.080 | 1.187 | 94.785 | 1.369 | 0.308* | 0.073* | ..... | | 0.188 |
| 188. | M. E. McDonnell, .. | 20,759 | ..... | 7.000* | 1.000* | 85.000* | 7.000* | ..... | ..... | ..... | | ..... |
| 188. | M. E. McDonnell,.... | 20,759 | Pa. Expt. Station Records, ..... | 20.120 | 2.120 | 76.130 | 1.300 | ..... | ..... | ..... | | 0.330 |
| 189. | Atlas Hercules and Cement Co., ..... | ..... | ..... | 6.000§ | ..... | 92.000 | 1.000 | ..... | ..... | $K_2O$ 1.00, ..... | | ..... |
| 190. | ..... | 65 | 309 MM 2d G. S., 1876-8, ..... | 8.980 | 0.070† | 49.316 | 40.463 | ..... | 0.014* | $FeCO_3$, 1.035, $FeS_2$ .030, Carb. matter 0.250, ..... | | ..... |
| 191 | ..... | 66 | 309 MM 2d G. S., 1876-8, ..... | 10.750 | 0.140† | 51.558 | 35.216 | ..... | 0.041* | $FeCO_3$ 1.450, $FeS_2$ .611, Carbon. matter 0.210, ..... | | 0.024 |
| 192. | ..... | 67 | 309 MM 2d G. S., 1876-8, ..... | 8.400 | 0.065† | 86.036 | 4.594 | ..... | 0.037* | $FeCO_3$ 0.538, $FeS_2$ .268, Carbon. matter 0.420, ..... | | ..... |

*Recalculated. †$Al_2O_3$ only. §Includes insoluble, ferric oxid and alumina.

| Compilation number. | Analyst. | No. of analysis. | References. | Insoluble matter. | Oxid of iron and alumina, $Fe_2O_3$ and $Al_2O_3$. | Carbonate of lime, $CaCO_3$. | Carbonate of magnesia, $MgCO_3$. | Sulfuric acid, $SO_3$. | Phosphoric acid, $P_2O_5$. | Other Constituents. | Undetermined. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 193. | ..... | 68 | 310 MM 2d G. S., 1876-8, ..... | 11.070 | 0.860† | 70.750 | 15.256 | ..... | 0.044* | $FeCO_3$ 1.398, $FeS_2$ .105, Carbon. matter, 0.120, ..... | 0.467 |
| 194. | ..... | 69 | 310 MM 2d G. S., 1876-8, ..... | 10.980 | 0.300† | 56.220 | 31.201 | ..... | 0.011* | $FeCO_3$ 1.305, $FeS_2$ .320, Carbon matter 0.120, ..... | ..... |
| 195. | D. McCreath, ..... | 392 | 76 M 2d G. S., 1874-5, ..... | 7.850 | ..... | 83.632 | 5.462 | ..... | 0.060* | $FeCO_3$ 1.188, $FeS_2$ .238, Carbon matter, 0.835, ..... | 0.735 |
| 196. | A. S. McCreath..... | ..... | 76 M 2d G. S., 1874-5, ..... | 5.650 | ..... | 51.920 | 41.071 | trace | 0.025* | ..... | 1.334 |
| 197. | A. S. McCreath,..... | ..... | 76 M 2d G. S., 1874-5, ..... | 11.260 | ..... | 47.890 | 39.585 | trace | 0.048* | ..... | 1.217 |
| 198. | A. S. McCreath,..... | ..... | 76 M 2d G. S., 1874-5, ..... | 13.490 | ..... | 51.603 | 32.917 | 0.368* | 0.027* | ..... | 1.595 |
| 199. | A. S. McCreath,..... | ..... | 76 M 2d G. S., 1874-5, ..... | 9.240 | ..... | 48.630 | 40.410 | 0.013* | 0.027* | ..... | 1.680 |
| 200. | Dr. Genth, ..... | ..... | 105 2d G. S., 1874-5, ..... | ..... | 2.360* | 50.076* | 43.150 | ..... | ..... | $SO_2$ 3.08, $Fe_2O_3$ 0.67 MnO 0.35, ..... | 0.314 |
| 201. | Dr. Genth, ..... | ..... | 105 2d G. S., 1874-5, ..... | ..... | 0.700* | 52.470* | 42.800 | ..... | ..... | $SO_2$ 1.12, $Fe_2O_3$ 1.21, MnO 0.44, ..... | 1.260 |
| 202. | H. Pemberton, Jr.,... | ..... | 110 2d G. S., 1874-5, ..... | ..... | 1.180† | 48.250* | 36.870 | ..... | ..... | $SO_2$ 12.13, $Fe_2O_3$ 0.38 | ..... |
| 203. | ..... | 352 | 94 $M_3$ 2d G. S., 1879-80, ..... | 4.680 | 4.660 | 70.589 | 1.740 | 0.068* | trace | ..... | 1.263 |
| 204. | ..... | 353 | 94 $M_3$ 2d G. S., 1879-80, ..... | 6.960 | 1.330 | 60.964 | 30.691 | 0.250* | 0.007* | ..... | ..... |
| 205. | ..... | 354 | 94 $M_3$ 2d G. S., 1879-80, ..... | 5.570 | 1.600 | 72.156 | 20.304 | 0.418* | 0.011* | ..... | ..... |
| 206. | S. S. Hartranft,..... | 784 | 308 MM 2d G. S., 1876-8, ..... | 0.760 | 0.426 | 97.651 | 1.131 | 0.095* | 0.089* | ..... | ..... |
| 207. | S. S. Hartranft,..... | 783 | 308 MM 2d G. S., 1876-8, ..... | 4.530 | 1.253 | 81.178 | 13.398 | 0.135* | 0.057* | ..... | ..... |
| 208. | ..... | 781 | 308 MM 2d G. S., 1876-8, ..... | 4.050 | 1.360 | 70.214 | 24.415 | 0.095* | 0.037* | ..... | ..... |
| 209. | ..... | 782 | 308 MM 2d G. S., 1876-8, ..... | 8.010 | 1.422 | 54.285 | 36.109 | 0.378* | 0.025* | ..... | ..... |
| 210. | McCreath, ..... | ..... | ..... | 2.850 | 0.700 | 94.290 | 1.530 | 0.140 | 0.030 | ..... | 0.460 |
| 211. | ..... | ..... | ..... | 0.250 | 0.900 | 53.190 | 45.450 | ..... | 0.020 | ..... | 0.190 |
| 212. | ..... | ..... | 79 Catalogue of Exhibits, ..... | ..... | ..... | 52.000 | 46.000 | ..... | ..... | $SO_2$ 1.000, ..... | 2.000 |
| 213. | G. G. Pond..... | ..... | 81 Catalogue of Exhibits, ..... | ..... | 0.170† | 98.160 | 1.080* | ..... | 0.050 | $SO_2$ 0.77, FeO 054,. | ..... |
| 214. | ..... | 286 | 82 $M_3$ 2d G. S., 1879-80, ..... | 31.520 | 5.384 | 60.214 | 1.664 | ..... | 0.155* | ..... | 1.063 |
| 215. | ..... | 287 | 82 $M_3$ 2d G. S., 1879-80, ..... | 41.940 | 5.761 | 49.178 | 1.816 | ..... | 0.120* | ..... | 1.185 |
| 216. | ..... | 288 | 82 $M_3$ 2d G. S., 1879-80, ..... | 53.810 | 8.298 | 33.482 | 1.967 | ..... | 0.192* | ..... | 2.251 |
| 217. | ..... | 289 | 82 $M_3$ 2d G. S., 1879-80, ..... | 15.720 | 2.550 | 71.732 | 7.621 | ..... | 0.030* | ..... | 2.347 |
| 218. | ..... | 290 | 82 $M_3$ 2d G. S., 1879-80, ..... | 6.530 | 1.206 | 89.642 | 1.816 | ..... | 0.025* | ..... | 0.781 |
| 219. | ..... | 393 | 295 MM 2d G. S., 1876-8, ..... | 24.780 | 4.393 | 63.969 | 4.244 | 0.963* | 0.325* | Fe as carbonate,... | 1.326 |

†$Al_2O_3$ only.

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 220. | ..... | 394 | 295 MM 2d G. S., 1876-8, ..... | 6.040 | 2.972 | 86.778 | 2.908 | 0.415* | 0.304* | Fe as carbonate,... | 0.583 |
| 221. | ..... | 418 | 295 MM 2d G. S., 1876-8, ..... | 5.640 | 0.340† | 88.139 | 1.854 | 0.893* | 0.053* | $FeCO_3$ 1.798,..... | 1.283 |
| 222. | ..... | 407 | 295 MM 2d G. S., 1876-8, ..... | 4.970 | 3.693 | 79.478 | 10.222 | 0.420* | 0.078* | Fe as carbonate,... | 1.139 |
| 223. | ..... | 418a | 295 MM 2d G. S., 1876-8, ..... | 3.950 | .359† | 92.298 | 1.483 | 0.243* | 0.041* | $FeCO_3$ 1.167, Carb. matter .550,..... | ..... |
| 224. | ..... | 419b | 295 MM 2d G. S., 1876-8, ..... | 12.020 | 1.626† | 54.321 | 23.088 | 0.318* | 0.117* | $FeCO_3$ 8.492. Carb. matter .980,..... | ..... |
| 225. | ..... | 419c | 295 MM 2d G. S., 1876-8, ..... | 10.760 | .403† | 69.264 | 13.773 | 0.265* | 0.108* | $FeCO_3$ 4.739, Carb. matter .590,..... | 0.098 |
| 226. | ..... | 83 | 296 MM 2d G. S., 1876-8, ..... | 17.779 | 4.440* | 52.940 | 16.060 | 0.220* | 0.133* | $FeCO_3$ 5.800, ..... | 2.637 |
| 227. | ..... | 424 | 296 MM 2d G. S., 1876-8, ..... | 3.850 | 0.261† | 90.544 | 2.134 | 1.160* | 0.030* | $FeCO_3$ 1.503, ..... | 0.518 |
| 228. | ..... | 84 | 296 MM 2d G. S., 1876-8, ..... | 13.360 | 11.600 | 50.160 | 18.494 | 0.383* | 0.275* | Fe as carbonate,... | 5.728 |
| 229. | ..... | 462 | 290 MM 2d G. S., 1876-8, ..... | 20.660 | 1.700† | 64.706 | 2.156 | 6.078* | 1.820* | Fe 4.274, Carb. matter 2.602, ..... | ..... |
| 230. | ..... | 380 | 291 MM 2d G. S., 1876-8, ..... | 3.740 | 1.986 | 90.803 | 2.738 | 0.210* | 0.110* | Fe as carbonate,... | 0.413 |
| 231. | ..... | 537 | 291 MM 2d G. S., 1876-8, ..... | 19.800 | 2.886† | 55.589 | 14.224 | 0.463* | 0.073* | $FeCO_3$ 6.835, ..... | 0.130 |
| 232. | ..... | 427 | 291 MM 2d G. S., 1876-8, ..... | 2.500 | 0.224† | 89.522 | 5.327 | 0.613* | 0.037* | $FeCO_3$ 1.812, ..... | ..... |
| 223. | ..... | 464 | 289 MM 2d G. S., 1876-8, ..... | 4.040 | 1.825 | 86.625 | 6.152 | 0.233* | 0.053* | Fe as carbonate, ... | 1.072 |
| 234. | ..... | 584 | 366 MM 2d G. S., 1876-8, ..... | 37.940 | 3.317 | 51.921 | 3.639 | 0.203* | 0.234* | $Mn_3O_4$ 0.586, $FeCO_3$ 3.069, ..... | ..... |
| 235. | ..... | 404 | 366 MM 2d G. S., 1876-8, ..... | 4.803 | 0.455 | 80.588 | 8.445 | ..... | 0.060* | $MnCO_3$ 1.400 $FeCO_3$ 3.314, $FeS_2$ 2.371,. | 0.564 |
| 236. | D. McCreath,..... | 448 | 286 MM 2d G. S., 1876-8, ..... | 9.180 | 3.211 | 72.623 | 12.614 | 0.398* | 0.011* | ..... | 1.963 |
| 237. | D. McCreath,..... | 540 | 286 MM 2d G. S., 1876-8, ..... | 6.220 | 2.871 | 85.732 | 5.098 | 0.260* | 0.085* | ..... | ..... |
| 238. | D. McCreath,..... | ..... | 287 MM 2d G. S., 1876-8, ..... | 9.730 | 5.301 | 69.160 | 15.535 | 0.115* | 0.039* | ..... | 0.12 |
| 239. | D. McCreath,..... | ..... | 287 MM 2d G. S., 1876-8, ..... | 11.510 | 6.830 | 74.803 | 6.734 | 0.130* | 0.160* | ..... | ..... |
| 240. | ..... | 923 | 300 MM 2d G. S., 1876-8, ..... | 5.240 | 5.196 | 80.393 | 5.653 | 0.600* | 0.305* | $MnCO_3$ 3.116, ..... | ..... |
| 241. | ..... | 924 | 300 MM 2d G. S., 1876-8, ..... | 17.850 | 5.870 | 69.000 | 5.387 | 0.230* | 0.330* | $MnCO_3$ 1.689, ..... | ..... |
| 242. | ..... | 336 | 299MM 2d G. S., 1876-8, ..... | 41.700 | 4.411 | 51.520* | 2.291* | 0.087 | 0.729 | ..... | ..... |
| 243. | A. S. McCreath,..... | ..... | 388 K 2d G. S., 1875, ..... | 22.520 | 7.148 | 48.823 | 20.621 | 0.507* | 0.117* | ..... | 0.264 |
| 244. | D. McCreath,..... | ..... | 388 K 2d G. S., 1875, ..... | 15.750 | 7.511 | 47.080 | 28.528 | 0.173* | 0.291* | ..... | 0.667 |
| 245. | D. McCreath,..... | ..... | 388 K 2d G. S., 1875, ..... | 13.300 | 3.306 | 68.837 | 14.649 | 0.245* | 0.112* | ..... | ..... |
| 246. | D. McCreath,..... | ..... | 388 K 2d G. S., 1875, ..... | 14.920 | 5.618 | 47.750 | 30.943 | 0.315* | 0.034* | ..... | 0.420 |
| 247. | D. McCreath,..... | ..... | 388 K 2d G. S., 1875, ..... | 17.380 | 2.929 | 72.866 | 3.813 | 0.388* | 0.140* | ..... | 2.484 |
| 248. | ..... | 355 | 94 $M_3$ 2d G. S., 1879-80, ..... | 28.800 | 4.145 | 64.392 | 1.816 | ..... | 0.115* | ..... | 0.732 |
| 249. | ..... | 356 | 94 $M_3$ 2d G. S., 1879-80, ..... | 65.470 | 8.903 | 19.785 | 3.518 | ..... | 0.217* | ..... | 2.107 |
| 250. | ..... | 357 | 94 $M_3$ 2d G. S., 1879-80, ..... | 75.220 | 4.432 | 17.696 | 1.589 | ..... | 0.078* | ..... | 0.885 |
| 251. | ..... | 358 | 94 $M_3$ 2d G. S., 1879-80, ..... | 80.950 | 4.988 | 11.196 | 1.664 | ..... | 0.083* | ..... | 1.119 |
| 252. | ..... | 763 | 293 MM 2d G. S., 1876-8, ..... | 4.015 | 1.520 | 91.982 | 1.664 | 0.228* | 0.027* | ..... | 0.564 |
| 253. | ..... | 948 | 293 MM 2d G. S., 1876-8, ..... | 0.990 | 2.720 | 94.643 | 1.144 | 0.070* | 0.034* | ..... | 0.399 |
| 254. | D. McCreath,..... | 546 | 347 MM 2d G. S., 1876-8, ..... | 38.240 | 6.002† | 42.357 | 4.037 | 1.265* | 1.351* | $FeCO_3$ 4.142, ..... | 2.606 |
| 255. | ..... | ..... | 80 Catalogue of Exhibits, ..... | 3.000 | ..... | 97.100 | 2.600 | ..... | ..... | ..... | ..... |
| 256. | A. S. McCreath,..... | ..... | 77 M 2d G. S., 1874, ..... | 21.500 | ‡0.743* | 73.180 | 4.370 | ..... | ..... | ..... | 0.207 |
| 257. | A. S. McCreath,..... | ..... | 77 M 2d G. S., 1874, ..... | 20.060 | ‡7.526* | 62.350 | 6.320 | ..... | ..... | ..... | 3.744 |
| 258. | A. S. McCreath,..... | ..... | 77 M 2d G. S., 1874, ..... | 15.890 | ‡1.899* | 77.890 | 2.830 | ..... | ..... | ..... | 1.491 |
| 259. | A. S. McCreath,..... | ..... | 77 M 2d G. S., 1874, ..... | 4.300 | ‡0.428* | 93.870 | 0.960 | ..... | ..... | ..... | 0.442 |
| 260. | L. De L. Moro, ..... | ..... | 110 C 2d G. S., 1874, ..... | 5.650 | ‡2.070 | 66.790 | 31.460 | ..... | ..... | $SO_2$ 0.30, FeO 0.37, | ..... |
| 261. | ..... | 386 | 308 MM 2d G. S., 1876-8, ..... | 16.650 | 2.034 | 65.702* | 10.298* | trace | 0.132 | $H_2O$ 0.250, Mno 0.321, $FeCO_3$ 3.933*, $FeS_2$ .065, ..... | 0.515 |

*Recalculated. †$Al_2O_2$ only. ‡$Fe_2O_3$ only.

| Compilation number. | Analyst. | No. of analysis. | References. | Insoluble matter. | Oxid of iron and alumina, $Fe_2O_3$ and $Al_2O_3$. | Carbonate of lime, $CaCO_3$. | Carbonate of magnesia, $MgCO_3$. | Sulfuric acid, $SO_3$. | Phosphoric acid, $P_2O_5$. | Other constituents. | Undetermined. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 262. | ..... | 431 | 308 MM 2d G. S., 1876-8, ..... | 18.210 | 7.454 | 68.707* | 1.670* | trace | 0.050 | $FeCO_3$ 3.587*, $FeS_2$ 0.41, $H_2O$ 1.055,... | ..... |
| 263. | ..... | 273 | 79 $M_3$ 2d G. S., 1879-80, ..... | 14.010 | 2.400† | 80.217* | 10.823* | 0.010* | 0.025* | FeO 1.1794, ..... | ..... |
| 264. | ..... | 274 | 79 $M_3$ 2d G. S., 1879-80, ..... | 10.890 | 2.320† | 78.915* | 13.138* | 0.008* | 0.028* | FeO 0.0864, ..... | ..... |
| 265. | ..... | 275 | 79 $M_3$ 2d G. S., 1879-80, ..... | 10.460 | 1.690† | 83.875* | 7.899* | 0.010* | 0.007* | FeO 0.585, ..... | ..... |
| 266. | ..... | 276 | 79 $M_3$ 2d G. S., 1879-80, ..... | 18.580 | 2.680† | 76.630* | 6.247* | 0.008* | 0.030* | FeO 1.098, ..... | ..... |
| 267. | ..... | 277 | 79 $M_3$ 2d G. S., 1879-80, ..... | 27.010 | 5.090† | 78.379* | 6.010* | 0.013* | 0.071* | FeO 2.304, ..... | ..... |
| 268. | Franklin Menges, .. | ..... | ..... | 0.530 | 0.030 | 83.120 | 8.230 | ..... | 0.100 | $K_2CO_3$ 4.23, ..... | 0.560 |
| 269. | ..... | 25,616 | Pa. Expt. Station Records, ..... | 0.560 | 1.440 | 98.350 | 0.160 | ..... | ..... | ..... | ..... |
| 270. | ..... | 25,617 | Pa. Expt. Station Records, ..... | 0.460 | 2.360 | 94.120 | 1.850 | ..... | ..... | ..... | 1.210 |
| 271. | ..... | 25,618 | Pa. Expt. Station Records, ..... | 6.420 | 0.600 | 91.480 | 0.900 | ..... | ..... | ..... | 0.600 |
| 272. | ..... | 25,619 | Pa. Expt. Station Records, ..... | 19.350 | 1.460 | 78.570 | 1.090 | ..... | ..... | ..... | ..... |
| 273. | ..... | 25,626 | Pa. Expt. Station Records, ..... | 4.910 | 3.490 | 80.960 | 9.620 | ..... | ..... | ..... | |

*Recalculated. †$Al_2O_3$ only.